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THE MEASUREMENT OF MAN

Minnesota Sigma Xi Lectures

The MEASUREMENT OF MAN

By J. A. HARRIS - C. M. JACKSON
D. G. PATERSON - R. E. SCAMMON

"Whether we are studying a material object, a magnetic field, a geometrical figure, or a duration of time, our scientific information is summed up in measures."—EDDINGTON

The UNIVERSITY OF MINNESOTA PRESS - 1930

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PRINTED IN THE UNITED STATES OF AMERICA
AT THE LUND PRESS, MINNEAPOLIS

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FOREWORD

THE history of science is still written chiefly in terms of man's struggle to know and master the world of nature about him. It is a story more dramatic and more significant in the history of the race than the story of sieges and lost battles and diplomatic victories. But significant as the achievement of man may be in the conquest of force and matter, of air and land and water, its telling may, in the years to come, give way before a new epic, the story of man's study and growing knowledge of himself as an individual and in the mass. Of this new story only a few chapters have as yet been written in comparison with what may still be before us to know and to write.

For such a study new norms and new techniques must be derived and applied. They are already being set up and, as in all sound scientific progress, they are built upon the disciplines and the knowledge that the world of scholarship has laid at the basis of past progress. And as in the past all fields of exact knowledge or bold scientific theory were based on measurement, that is, upon mathematics, so in the study of himself and his kind, man seeks the aid of mathematics and develops biometry as the handmaid of his newer studies of himself and of all animate things.

The significance of the chapters of this book, delivered first as lectures under the auspices of Sigma Xi at the University of Minnesota by four scientists in different fields, is twofold. They add some little portion to the long story, still incomplete, of man's conquest of the secrets of his own nature, and each in its own way gives new testimony to the truth of the quotation from Eddington on the title page.

The members of Sigma Xi at Minnesota can justly feel a satisfaction in having initiated the effort that gave us first the

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spoken word and now this delightful and interesting volume in permanent form.

This pleasure is tempered by the knowledge that our associate, Dr. J. Arthur Harris, has in this volume given us the last inspiring example of his abounding knowledge and rare powers of exposition that we shall have directly from him. Dr. Harris died on April 24, 1930.

C. H. Bailey, *President,*
Minnesota Chapter, Sigma Xi

University of Minnesota
Minneapolis

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I

THE MEASUREMENT OF MAN IN THE MASS

By J. Arthur Harris

THE MEASUREMENT OF MAN IN THE MASS

BY

J. ARTHUR HARRIS

I. INTRODUCTORY

WHILE Pope in the lines of his second epistle of the "Essay on Man"——

> Know then thyself, presume not God to scan!
> The proper study of mankind is man——

struck a chord that still vibrates after nearly two centuries, we may doubt whether his famous essay has had any very important influence on the development of the science of man as we know it today. To biologists, indeed, Pope's dictum seems only a half truth. We maintain that the proper study of mankind is not man as a creature apart, but man in his relations to his physical and biological environment. We hold further that in studying man we should consider him impartially, regarding him as one of the species of the animal kingdom, and proceeding in our investigation in the same way that we do in our study of other organisms. If such a course gives us a finer understanding of the problems of mankind, if it adds to our appreciation of the orderliness of the living universe, if it creates a new interest in mankind, it will have justified itself.

In the light of our present scientific knowledge of man, Pope was certainly wrong when he wrote:

> The science of human nature is, like all other sciences, reduced to a few, clear points; there are not many certain truths in this world. It is therefore in the anatomy of the mind, as in that of the body; more good will accrue to mankind by attending to the large, open, and perceptible parts, than by studying too much such fine nerves and vessels, the conformation and uses of which will forever escape our observation.

Today all these finer nerves and vessels have not merely been observed and named, but their conformation described and mapped, and the uses of many of them so definitely deter-

mined that the surgeon may use his knife with intelligence and confidence. Furthermore, the internal organs, the bones, the muscles, the vessels, and the nerves of the human body have been compared in such a detailed way, both as to structure and as to function, with those of the animal body, that the results of investigations on the lower animals may be directly applied in the solution of many problems that are fundamental to the physical well-being of mankind.

But it is not with the marvelous details of human structure and function nor with the physical and mental characteristics and behavior of human individuals as such that I have to deal. Instead, it is my privilege to invite attention to the problem of *the measurement of man in the mass.*

In considering man in the mass, I am running counter to a deep-seated human interest. Man's interest in man is highly personal. It centers largely in the individual, or, at most, in a very limited group of individuals.

Interest in personalities has various consequences. It is the foundation of the family and of the clan and of all the more complex social organizations. Or possibly the necessity for family life in a biological organism with a prolonged period of infantile helplessness has been the underlying cause of the intense interest in individuals as such. The answer to this question I must leave to the ethnologist and sociologist.

The deep-rooted interest of individuals in individuals has led to many absurdities in our conduct. Innumerable camera records play a large part in determining the success or failure of political candidates. A half-tone portrait of the inventor, manufacturer, manager, or agent is potent in the sale of razor blades, talcum powder, or cigars, notwithstanding the fact that few would seriously assert that the razor blade is keener, the powder more cooling, or the cigar more enjoyable because the genial countenance of the man to whom the checks are to be endorsed is known to the purchaser. It is the innate interest in individuals that lends commercial value to the portrait,

which, in the popular magazines, accompanies the assertion, "I can make you a powerful speaker," or "I can make you a gifted writer," or the even more seductive suggestion, "Let me double your income."

The depth of this personal interest in specific individuals may have actually retarded impersonal scientific investigation and generalization to the disadvantage of science and of mankind itself. The scientific man, in his capacity as an investigator, is not interested in an individual as such. His interest lies in the fact that the individual taken with a large number of others may serve as a basis of generalization. We shall see as we proceed that human attributes are rigidly lawful in their frequency of occurrence, and that when we consider man in the mass, many definite relationships can be detected and quantitatively expressed that would escape our knowledge if we limited our attention solely to the consideration of individuals.

Science, as it develops, advances through the stages of observation, description, and experimentation to the stages of measurement and calculation. Our object is to consider the methods, and, in some small part, the accomplishments of those students of mankind who have studied human individuals for the purpose of basing broad and permanently valuable mathematical generalizations on masses of measurements.

II. INDIVIDUALS AS REPRESENTATIVES OF GROUPS

While generalizations concerning mankind must be grounded on a broad study of human beings, it is obviously impossible for the investigator to examine all human individuals. He must of necessity base his generalizations on samples of mankind. Having selected samples that he believes to be typical of the population under investigation, he must find some mathematical description of the characteristics of these samples.

Generally he cannot satisfactorily measure a sample as a whole, or *en masse*. If he could measure the sample as an en-

tity, for instance, by determining the total weight of all the individuals of a group at once, the result would be mentally incomprehensible and non-comparable from sample to sample, because the various samples would generally contain different numbers of individuals. For practical reasons, therefore, he must measure the individuals, and from the measurements of the individuals compute the characteristics of the group in such terms that the mathematical constants for any one sample will be comparable with those of any other sample that he, or any other investigator, may consider. We shall see later that there are many advantages in retaining and utilizing all the information concerning the individuals.

A first great advantage of retaining the information concerning individuals must be grasped at the outset. When inspected in a casual way the individuals that constitute a sample seem to show chaotic irregularities with respect to any characteristic that we choose to consider. When actual measurements of this character are arranged in the order of their magnitude, and the number of individuals of each magnitude counted, it is found that the sample is not chaotic but orderly. Thus, for example, the second and fifth columns of Table 1, the two polygons and curves of Figure 1, and the second column of Table 6 show that the frequencies of various statures of men and women are distributed in a highly orderly manner. Few individuals of very small or very great stature occur. The great mass of men and women have statures differing but little from the average magnitude. Above and below this average magnitude the frequencies decrease in such an orderly manner that they can be expressed reasonably well by the mathematical equations represented by the flowing lines in Figure 1.

Similar evidences of orderliness in the distribution of the frequency of human characteristics are shown in Figure 5, which shows the percentage of cases in which English mothers bear 0, 1, 2, 3, etc. children, and in Table 3, which gives the age of men and women at marriage. These two latter series cannot

be represented by the same mathematical equation as that employed for stature in Figure 1, but nevertheless show an orderliness of distribution that is our only concern at present.

While such frequency distributions furnish an illuminating picture of the measurement for all the individuals of the sample, and enable us to see by inspection what the minimum and maximum and the most common value, or mode, are, we require a system of statistical constants to describe the masses of individuals. Such constants, summarizing the characteristics of the sample as a whole, reduce the comparison of different samples of mankind to the simplest terms.

III. THE MEASUREMENT OF MASSES OF MANKIND IN TERMS OF STATISTICAL CONSTANTS

The first information required concerning a characteristic or measurement of any group of individuals is some knowledge of its order of magnitude. This process of determining some constant that shall furnish a measure of the size or magnitude of the individuals of a series may be called the measurement of type.

The Measurement of Type in Masses of Mankind

The desire to obtain information about classes of individuals leads us to a consideration of one of the simplest constants used in measuring the characteristics of man in the mass. This is the average magnitude of the characteristics under consideration.

The average or mean value of a series of measurements is so familiar to all intelligent people that it need not be treated in great detail. It summarizes in one simple constant the available information concerning the magnitude of the character—height, weight, span, head length, breadth, or circumference—which has been measured on the N individuals of a given sample. The average or mean may not correspond exactly to any one individual in the series, but it is in a limited way typi-

cal of all individuals, since it is made up of $\frac{1}{N}th$ part of the magnitude of each measurement.

Let us select as an illustration a characteristic that is so familiar that understanding of the method of dealing with and of reasoning about series of measurements will not be confused by the novelty of the measurement itself.

Suppose we desire to determine whether men are taller than women. We cannot measure all men and all women. We must be content with a sample of each class. Here the distinction between the characteristics of individuals and the characteristics of groups of individuals may be strikingly illustrated. In order to have an equal number of mature men and women and to have these in pairs that are selected without bias as far as we are concerned, we utilize the statures of 1,079 British husbands and wives, as reported by Pearson and Lee.[1]

It will be illuminating to arrange the men and the women in order according to their statures and to note the frequency of individuals of each class of stature. The frequencies of men and women of different statures are shown as actual numbers in the second and fifth columns [2] and as percentages of the total number of each sex in the third and sixth columns of Table 1. The fourth and seventh columns of this table need not receive attention for the moment. A comparison of the second and the fifth or of the third and sixth columns shows that the wives have a far lower minimum (52-53 inches) and maximum (70-71 inches) stature than the husbands, who range from 58-59 inches to 75-76 inches. In both sexes, however, there are statures ranging from 58 to 71 inches.

We may further compare these data for men and women by entering the full range of stature for both sexes along a base

[1] K. Pearson and Alice Lee. On the laws of inheritance in man. I. Inheritance of physical characters. Biometrika, 2:357-462. 1903.

[2] When an individual falls exactly on the borderline between two classes, one half is placed in each class in order to secure the most exact numerical constants possible.

TABLE 1

PERCENTAGE FREQUENCIES OF VARIOUS STATURES IN 1,079 BRITISH HUSBANDS AND WIVES AND AVERAGE STATURE OF WIVES OF DIFFERENT CLASSES OF HUSBANDS AND AVERAGE STATURE OF HUSBANDS OF DIFFERENT CLASSES OF WIVES

STATURE IN INCHES (WIVES OF HUSBANDS)	ACTUAL FREQUENCY OF HUSBANDS	PERCENTAGE FREQUENCY OF HUSBANDS	AVERAGE STATURE OF WIVES OF HUSBANDS	ACTUAL FREQUENCY OF WIVES	PERCENTAGE FREQUENCY OF WIVES	AVERAGE STATURE OF HUSBANDS OF WIVES
52–53	....	....	....	1.5	.14	65.83
53–54	....	....	....	.5	.05	66.50
54–55	....	....	....	1.0	.09	67.25
55–56	....	....	....	2.5	.23	64.20
56–57	....	....	....	6.5	.60	65.58
57–58	....	....	....	18.5	1.71	66.40
58–59	.5	.05	61.00	34.5	3.20	66.01
59–60	2.5	.23	60.30	82.0	7.60	66.54
60–61	4.5	.42	61.39	138.5	12.84	67.14
61–62	9.5	.88	61.29	162.5	15.06	67.39
62–63	33.0	3.06	61.47	184.0	17.05	67.68
63–64	43.0	3.98	61.77	162.5	15.06	68.10
64–65	75.5	7.00	61.65	129.5	12.00	68.07
65–66	123.5	11.44	61.93	80.0	7.41	68.57
66–67	146.5	13.58	62.01	44.0	4.08	68.85
67–68	140.5	13.02	62.23	17.0	1.58	69.19
68–69	162.5	15.06	62.71	8.0	.74	69.88
69–70	124.0	11.49	63.18	4.5	.42	71.33
70–71	102.5	9.50	63.53	1.5	.14	71.17
71–72	57.0	5.28	63.24	....	....	....
72–73	34.0	3.15	64.00	....	....	....
73–74	12.5	1.16	63.96	....	....	....
74–75	5.0	.46	63.85	....	....	....
75–76	2.5	.23	63.90	....	....	....
Total	1,079.0	99.99	....	1,079.0	100.00	....

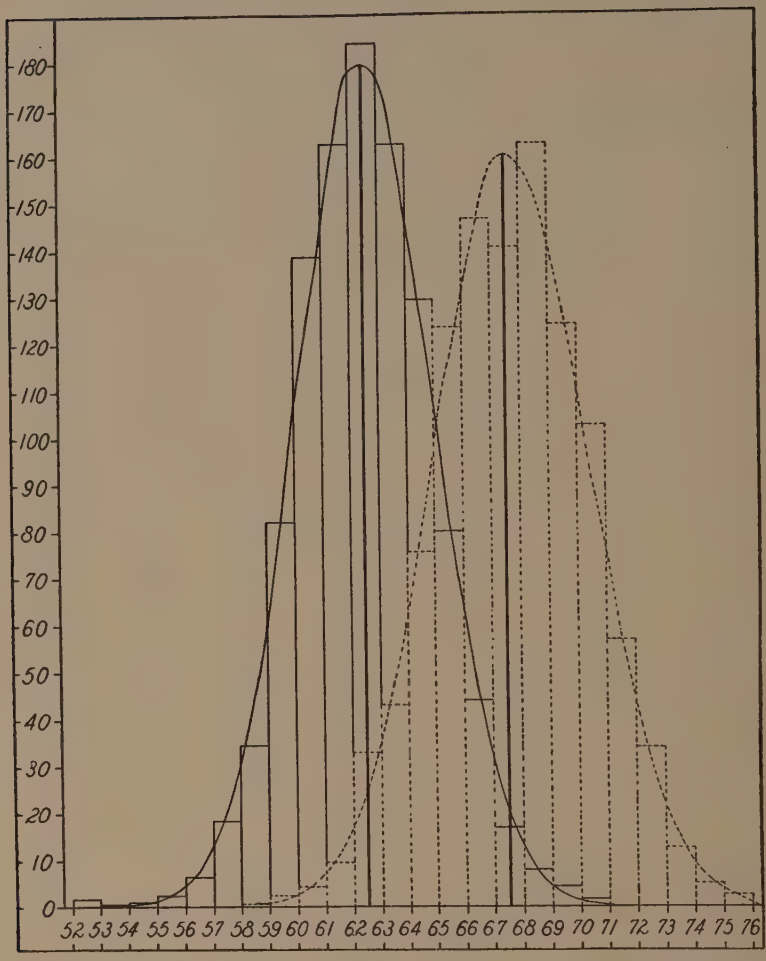

FIG. 1.—Statures in inches of 1,079 men and women (husbands and wives) who were parents of adult children. The flowing lines are mathematically fitted curves. Solid lines represent women, broken lines represent men. See also Fig. 2.

line and representing the frequencies of each class of stature by the height of a bar above this base line. To distinguish between men and women we represent the numbers of each class of the former by broken bars and the numbers of each class of the latter by solid bars. The numerical significance of the posi-

tions of these bars is indicated by the scale at the left of Figure 1. The flowing lines (solid for women and broken for men) represent mathematical equations fitted to the actual frequencies. These will receive attention later.

These two frequency distributions, as they are called, show clearly that the majority of men are taller than the majority of women, but that the two series of measurements are transgressive. A considerable number of women are taller than many men.

It is now desirable to arrange these measurements in a different way. In Figure 2 the scale at the bottom shows the stature of the husband, while the scale at the side shows the stature of the wife. Each solid dot on the surface bounded by these two scales shows the position of each pair of men and women with reference to the two scales. By dropping a line from any dot to the scale at the bottom, the stature of the husband may be ascertained. Similarly, by projecting a line from the same dot to the scale at the left, the height of the wife may be determined.

Now if wives and husbands were on the average of the same stature, we should expect the stature of the wives of husbands who were 64 inches tall to be distributed with some regularity above and below 64 inches. The compartments of the field that represent equality of stature of husbands and wives are designated by heavy bars for all heights of husbands up to 71 inches. The great preponderance of the solid dots fall below these heavy bars, showing that the wives of men of any given stature are generally, but by no means invariably, shorter than their consorts.

Since some individual women are taller than some individual men, the only way in which we can draw a generalization concerning men and women as classes is to determine some constant describing stature which shall contain information covering each of the individuals measured but which shall de-

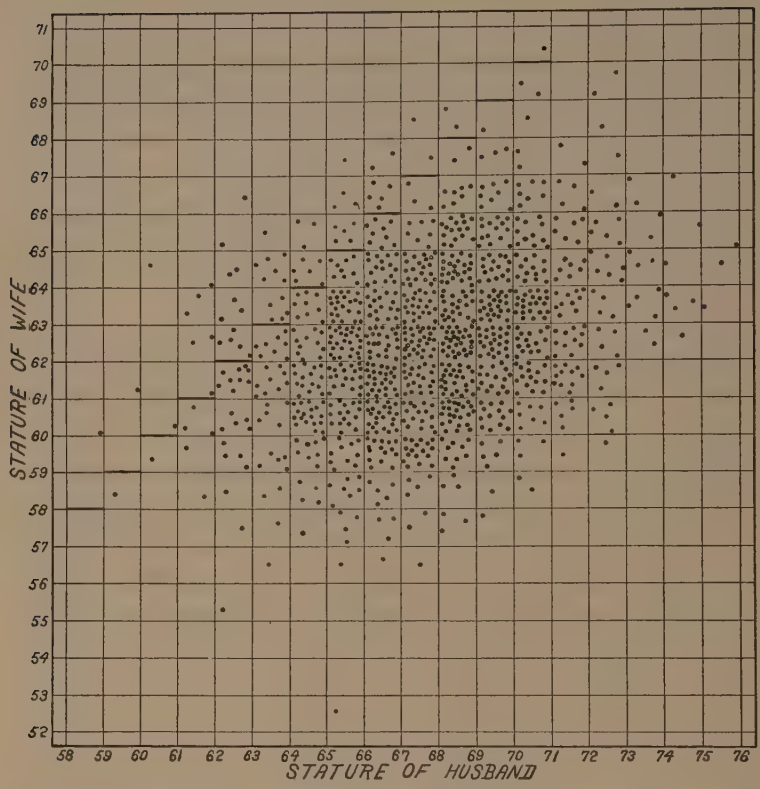

FIG. 2.—Relationship between the statures of 1,079 individual husbands and wives. Each dot represents one pair. See also Fig. 1.

scribe the characteristics of the samples as a whole rather than those of the individuals as such.

By way of illustration let us apply this conception of the average to the measurements shown in Figure 2. We may calculate the average stature for the wives of husbands of different heights, and in order to avoid any show of partiality, we may also calculate the average stature of husbands of each class of wives. Columns 4 and 7 of Table 1 give the results.

If we compare the average statures of the wives of the husbands of any class with those of their husbands as given in the

first column of the table, we will see that generally, but not invariably, the average statures of the wives are less than those of their husbands. If we compare the average heights of husbands, as shown in the seventh column, with the heights of their wives, as shown in the first column, we note that in all cases the average statures of the husbands are greater than those of the wives.

These results are represented in Figure 10, which will be more readily understood later. For the moment it is sufficient to note that while we do not get absolutely uniform results when we deal with the relatively small groups secured by dividing our available records into classes, there is strong evidence for a real differentiation in the stature of men and women.

We may summarize the results for all of the available data and further illustrate the usefulness of the average as a descriptive constant [3] by presenting the mean statures of these parents and their adult children in Table 2.

TABLE 2

COMPARISON OF STATURE OF MEN AND WOMEN ON THE BASIS OF PEARSON'S FAMILY HISTORY DATA

	PARENTAL GENERATION	FILIAL GENERATION	DIFFERENCE
Men	67.663±.055	68.713±.049	1.050±.074
Women	62.513±.049	63.818±.048	1.305±.069
Difference	5.150±.063	4.895±.046	.....

These averages show at a glance that the husbands who are fathers of adult children are 5.150 inches taller than their wives. This is shown graphically on Figure 1 by the relative positions on the base scale of the two heavy vertical lines,

[3] The constants are based on 1,079 fathers and mothers and on 1,401 brothers and sisters, in order to have the measurements for the two sexes in pairs in both generations.

which represent the average statures for the two frequency distributions.

The probable error in the table indicates to the statistician the trustworthiness of this difference as a basis for generalization. He sees that the difference cannot be taken as absolutely true for all men and women of the British population. This is shown to be the case by a comparison of the results for the second generation, in which there is an excess of 4.895 inches of male over female stature.

The suggestion may be made that this is merely putting into figures what we already know from general observation, and that the calculation of means has done nothing to increase our knowledge of stature. In reply to this criticism, suppose that we glance at the difference in the average statures of the two generations as shown in the right-hand column of the table. Here we see that sons are over an inch taller than their fathers and that daughters are nearly an inch and a half taller than their mothers. The original constants show that all the physical measurements studied were larger in the filial generation.

Two features of the results are worthy of our consideration. They show that a comparison of averages may reveal significant differences that would certainly have escaped our unaided observation. They bring us face to face with a new group of problems. Why is the stature of the children greater than that of their parents? Is it due to recent changes in the level of nutrition, conditions of sanitation, or lowered requirements of labor during the period of physical growth? Or does it mean that the younger generation has a more erect posture due to differences in exercise and other habits of life? Or, again, may it mean that natural selection has acted differently in the two generations? Such are the problems that spring into being in the mind of the biometrician as he considers these results of measurements of man in the mass. For their solution, further studies by kindred methods are required.

Let us examine another series of averages that shows how

the determination of this simple statistical constant may advance our knowledge of man. Figure 3 shows the average body lengths in centimeters and body weights in ounces at birth of six series of newborn infants.[4]

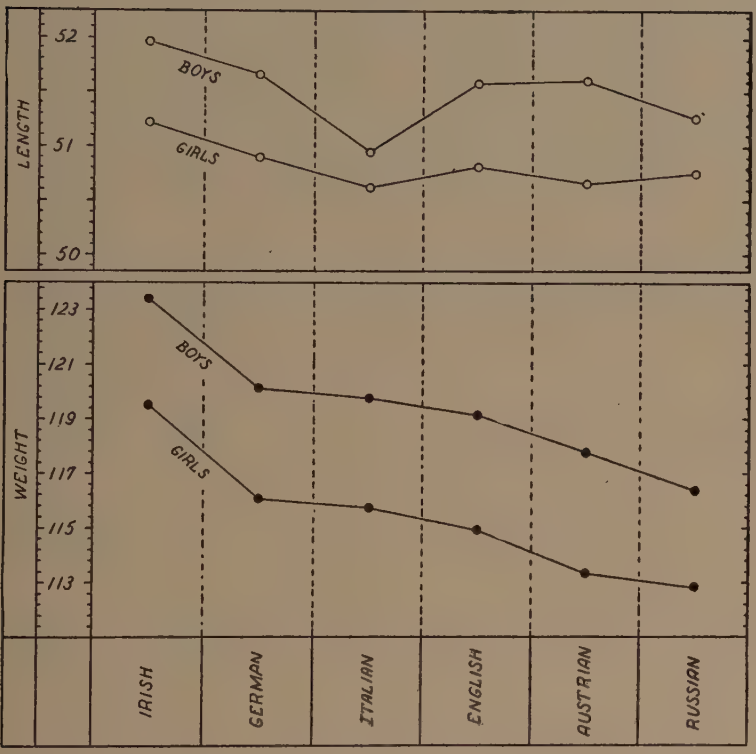

FIG. 3.—Average weight in ounces and average length in centimeters in newborn infants of various nationalities.

[4] The average lengths (solid dots) and breadths (circles) of the heads of these infants appear in Figure 7, to be discussed later. On the average, the length of the head is much greater than the breadth at birth. The averages for the left-hand side of the diagram (girls) are somewhat lower than those of the right-hand side (boys). Thus the difference in the size of the male and female infant at birth is slightly evident in head size as well as in body weight and length. The interesting feature of the result is that the differences are not as large as most people, including many medical men, believe.

The infants of the six nationalities are probably as nearly comparable as can be secured, since both of the parents were born in the European country indicated, while the infants themselves were born in one hospital (the Sloane Hospital for Women, in New York City) during the period from 1890 to 1921, inclusive. This figure brings out clearly the differences between the average weights of boy and girl babies at birth. It also suggests that the weights and lengths differ from nationality to nationality.

It is worth while to consider this point further, and to inquire especially as to whether the differences from nationality to nationality are of equivalent magnitude for the two characters dealt with.

The constants in Figure 3 are not comparable because of the fact that the measures of length and of weight are necessarily given in quite different units. We may arrive at a standard for the comparison of the two characters by taking as a base the averages of the average lengths or weights of the infants of the two nationalities that are being compared, and by expressing all of the individual differences as percentages of these standards. This makes all the differences strictly comparable, and we may lay them side by side in Figure 4.

In this figure the two nationalities to be compared are represented on the two axes. The differences in the mean weights of the infants of the two nationalities are represented by the deviations of the solid dots from the transverse bars. The differences in the lengths are shown by the position of the circles with reference to these transverse lines. The figure is divided into two parts. The left half shows the results of comparisons for girls; the right half the comparable results for boys.

Since the transverse bars represent the average value of either length or weight for the two nationalities compared, the deviations of the solid dots above or below these standard values show the amounts by which the infants of the two nationalities are differentiated. The figure may be read from either of

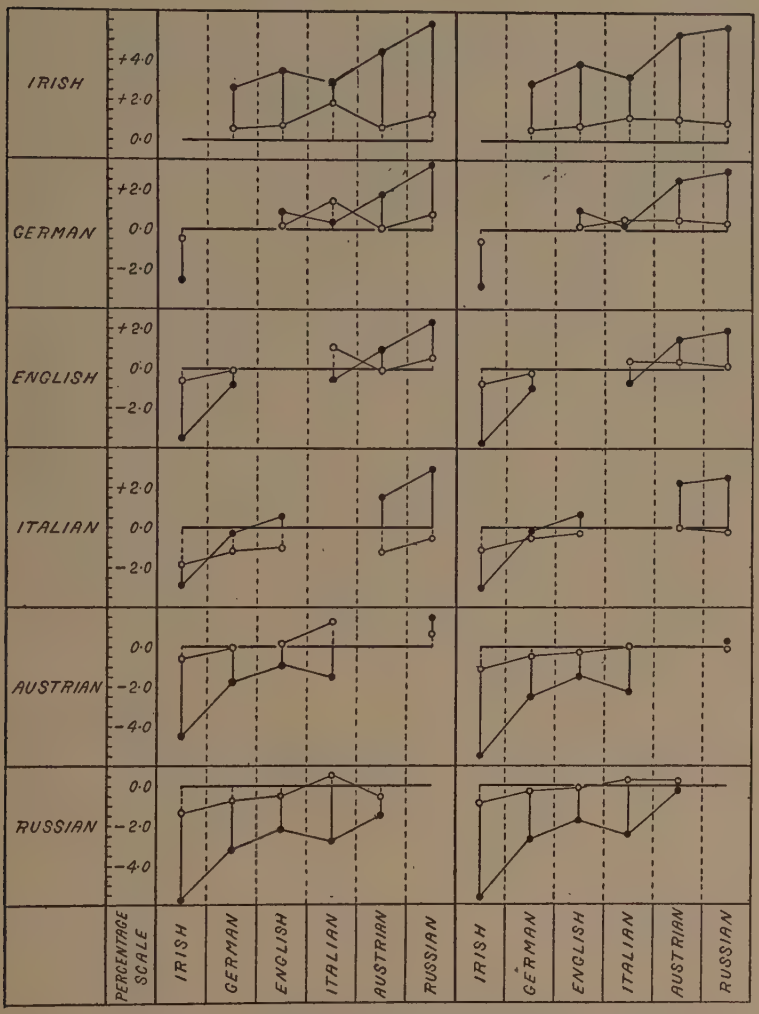

FIG. 4.—Comparison of average body weights (solid dots) and average body lengths (circles) in newborn infants of various nationalities. All differences are reduced to a percentage basis.

the two scales. It is convenient to take the nationalities that are given at the left in association with a numerical scale.

The upper panels of the figure show that Irish boys and

girls are from somewhat more than 2 to nearly 5 per cent heavier than infants of German, English, Italian, Austrian, or Russian parentage. Similarly, the lower panels show that the children of Russian parentage (chiefly Russian Jews) are from practically 0 to practically 5 per cent lighter than those of Irish, German, English, Italian, or Austrian extraction. The German, English, Italian, and Austrian races occupy intermediate positions. Clearly, such results could not have been obtained without the actual calculations of some precise constants summarizing the weight of the several series of infants.

While popular interest in the characteristics of the newborn infant centers in three inquiries, familiar in social courtesies—sex, weight, and well-being of mother and child—scientific research demands more intensive consideration of length of infants. An examination of the position of the circles on Figure 4 makes it quite clear that Irish infants are slightly longer than those of the five other nationalities with which they are compared. In no other case, however, does the birth length differ consistently from class to class.

At first thought the inconsistency of the results for birth length with those for birth weight might seem to throw doubt on the validity of the conclusions drawn from the constants for weight. My own interpretation is quite different. I believe that the findings show that there is a real differentiation between the infants of various origins with respect to these two characters.

Differentiation is greater for weight than for length. The exceedingly small differences found for length are, indeed, one of the most interesting results of the investigation. In only one of the thirty comparisons that have been made for the two sexes is the difference in mean length as much as one centimeter. Thus while a detailed study of the probable errors of the differences shows that in some cases there is a statistically significant difference in the birth length of the different nationalities, the birth length is, practically speaking, constant. To

this point I shall return, after we have had the advantage of knowing something of the measurement of variability.

Before leaving the mean or average as a constant describing man in the mass, we should note certain misconceptions concerning its value as representative of the typical individual of the series. It is quite natural for one who is not trained in dealing with masses of measurements to think that the average individual is the typical individual of the sample. This may or may not be true, as an illustration will readily show.

In Figure 5 the scale along the base represents the number of children borne by 4,418 English women, as recorded by Pearson and his co-workers,[5] while the vertical scale shows the percentage frequencies of families with various numbers of children. Two sets of relative or percentage frequencies are given. The circles represent those based on the total 4,418 married women, while the solid dots represent the percentage frequencies based on the 3,643 women who bore at least one child.

In the first case the average number of children per wife is 3.493, while in the second case it is 4.237. These means are shown by the position of the two heavy bars on Figure 5. In both cases the most common, or modal, number of children is far lower. If all women are included, complete sterility is the most common condition; if attention be limited to women who bore at least one child, one is the modal class. While the distribution of the frequencies of numbers of children per mother does not form a symmetrical system, as do the frequencies for stature, the orderliness of the frequencies is quite evident.

Our discussion of the mean and the mode will have made it quite evident that for a comprehensive description of the characteristics of a sample of individuals, we cannot be satisfied with the mean alone. Valuable as it is, it fails utterly to describe in all desirable details the characteristics of the individuals of which the sample is made up.

[5] K. Pearson, Alice Lee, and L. Branley Moore. Genetic (reproductive) selection: inheritance of fertility in man, and of fecundity in thoroughbred racehorses. Phil. Trans. Roy. Soc. Lond. A., 192:287-330. 1899.

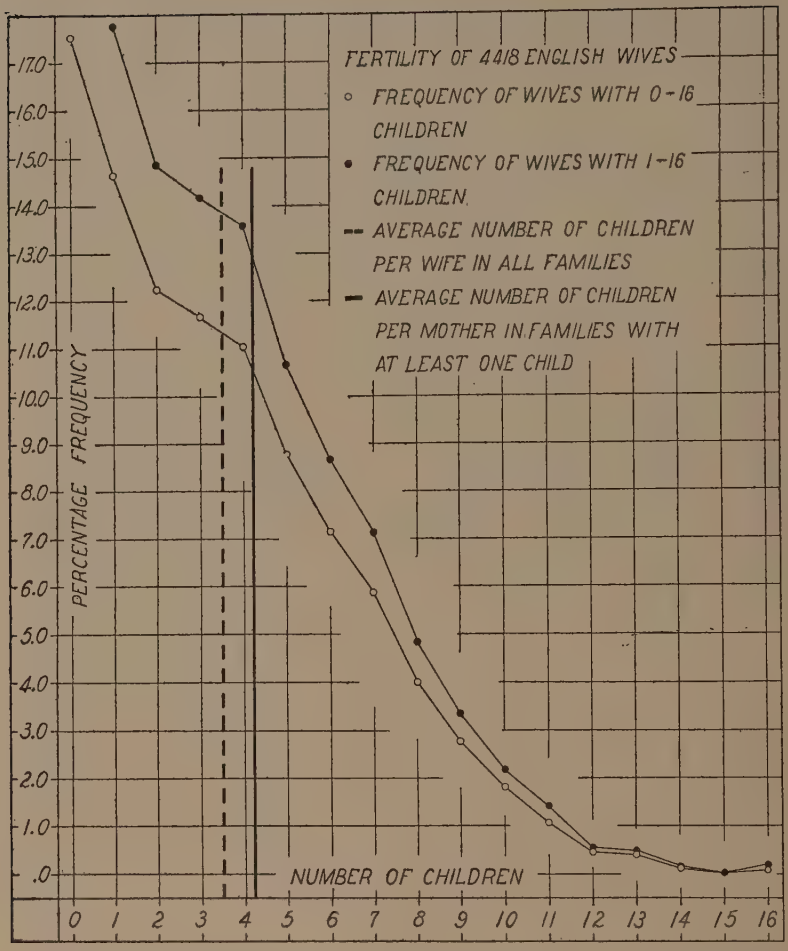

FIG. 5.—Percentage frequencies of numbers of children born to 4,418 English mothers. Circles represent percentage frequencies based on the entire series; solid dots represent percentage frequencies based on the 3,643 women who bore at least one child.

THE MEASUREMENT OF DIVERSITY IN MASSES OF MANKIND

The foregoing brief discussion has been sufficient to show that when masses of individual measurements are available the average magnitudes may reveal differences between groups

that otherwise would have entirely escaped our attention. They have enormous value for the comparison of races, social classes, and many other kinds of groups of human beings. They are, however, wholly inadequate for a full description of man in the mass.

One of the most salient characteristics of mankind is the diversity that obtains among the individuals of any population or of any sample. In many ways the diversity between individuals of any national, racial, social, or family group is of greater interest than the average value. Everywhere the exigencies of life have sharpened those human faculties that are of service in the discrimination of differences between individuals. This is evident among primitive men. It is perhaps as evident in the plainsman or trapper as in the metropolitan social leader. Through highly developed power of appreciating differences between individuals, we have come to believe that no two human beings are exactly alike. All this enduring interest in human diversity justifies an effort on the part of the scientific man actually to measure in quantitative terms the amount of the differences between individuals.

Individuals may be as certainly recognized as they are, largely because they have many attributes that may differ from person to person. Two men may be identical in stature but different in weight. If they are identical in both stature and weight, they may differ in head form, hair color, eye color, or in innumerable other features. These finely graduated characteristics, and their limitless combinations, we have, in the course of the evolution of our senses, learned to distinguish when we observe people. The detective may never forget the face, the voice, the hands, the posture, or the gait of a criminal he has once seen, and may recognize him at a glance as he walks disguised through a great metropolitan railway station.

In dealing with man in the mass our problem may be simplified by considering one characteristic at a time. Later we may hope to treat many characteristics simultaneously. In much of

our observation and study of human beings, we compare two only at one time. When we study man in the mass we must perforce adopt a different kind of comparison. We cannot compare each individual of our sample with every other one because of the laboriousness of the process.

We may illustrate the difficulty of making individual comparisons by noting that if we are interested in four children, six comparisons are possible. This number may be readily made. But if there be ten children, forty-five individual sets of differences must be considered. More generally, if we have a sample of n individuals to be compared among themselves, $\frac{1}{2}\, n\, (n-1)$ combinations may be realized. If 100 are included in the sample, 4,950 comparisons result. Often we deal with samples of thousands. For example, the series of measurements of newborn infants from which earlier illustrations were drawn contains about 10,000 babies. If all of these were contrasted by pairs, the possible combinations would number nearly fifty million!

Measures of Absolute Variability

To obviate the insuperable difficulty of large numbers of combinations, we must make our comparisons in some less direct but equally satisfactory way. We do this by comparing each individual with the average of all the individuals of our sample. This is a wholly legitimate method of procedure since the average represents one nth part of the measurement of each individual of our series.

If we designate the measurement of any one individual by x, we can indicate the value of that measurement in relation to the standard of the whole series clearly by $(x - \bar{x})$, the bar denoting a mean. Since this difference will have the sign of the larger value, it shows at a glance whether the particular individual under consideration is larger or smaller than the average.

As a matter of fact, this method of comparison is merely a formal expression of one with which we are quite familiar in

daily life. When we say a man is tall, we mean that he is taller than the average of the group to which we consider that he belongs. Or, in other words, we imply that $(x - \bar{x})$ is positive in sign. The advantage of the evaluation of $(x - \bar{x})$ is that it tells us at once just how much taller the man is than the average. If we say a man is short we mean that $(x - \bar{x})$ is negative. If numerical values are substituted for x and $\bar{x}$, we know how much the man falls short of the average status of the whole sample. This method of expression has the advantage of showing the exact position of each individual in the series. Its use is consistent with the assumption that no individual is absolutely large or small, but only relatively large or small.

Because of mathematical reasons, which cannot be set forth in detail here, the average value of $(x - \bar{x})$ for all the N measurements that have been made is not the most suitable constant to express the diversity of the values of x. A better and almost universally accepted constant is the square root of the mean of the squares of the differences between the individual cases and the average value. Thus

$$\sqrt{\frac{S[(x-\bar{x})^2]}{N}}$$

This is called the standard deviation or, for brevity, σ.

The standard deviation is a quantitative measure of the deviation of the individuals of a sample from their mean. In Figure 1 the amounts of the deviation of each class of stature from the mean stature of husbands and wives are expressed in terms of the number of individuals for each class of deviation. These are summarized in two single constants when we say that the standard deviation of stature is 2.79 inches for husbands and 2.39 inches for wives.

As a second illustration we note that the standard deviations given in Table 4, to be discussed in detail later, furnish in two single constants exact measures of the variability in age at marriage from department to department in France.

Finally this central panel of Figure 7 shows, by the positions

of the solid dots and circles with reference to the scale at the left, the standard deviations of the length (solid dots) and breadth (circles) of the head of newborn infants of various nationalities. The generally higher position of the solid dots shows that length is more variable than breadth. A glance at the upper panels shows, however, that the average length is greater than the average breadth. This makes necessary a correction that will be discussed below.

Measures of Relative Variability

It will have been clear from the preceding illustrations that in some cases in which we might like to make comparisons our standard deviations have been expressed in quite different terms. For example, the standard deviation of the length of the newborn infant may be given in centimeters, whereas the standard deviation of body weight at birth may be recorded in ounces. It is of interest to know whether infants differ among themselves more with respect to weight than with respect to length, and if so, what the amount of this difference is.

We may render these measures of variability, which are given in quite different terms, comparable by expressing them as percentages of their average values. Thus the standard deviations of weight and length, σ_w and σ_l, are not comparable values because w and l are not measured on comparable scales. But if we take $100\sigma_w/\bar{w} = V_w$, and $100\sigma_l/l = V_l$, where the V is to be read as the coefficient of variation, we may render our two measures of variability quite comparable.

Let us examine some results in terms of this new scale of measurement. Consider first the variability of the newborn infant with respect to body weight and body length. A comparison of the standard deviation for birth length and birth weight is meaningless, since one is in centimeters while the other is in ounces. When expressed in terms of the coefficient of variation, the two measures of variability are rendered comparable.

The results are shown for six nationalities in Figure 6. The

circles represent the coefficients of variation for body length, while the solid dots show the magnitudes of the coefficients of variation for body weight. A glance at Figure 6 below shows at once that the coefficients of variation for body length are from about 4.0 to about 4.5 per cent for boy and from 3.9 to

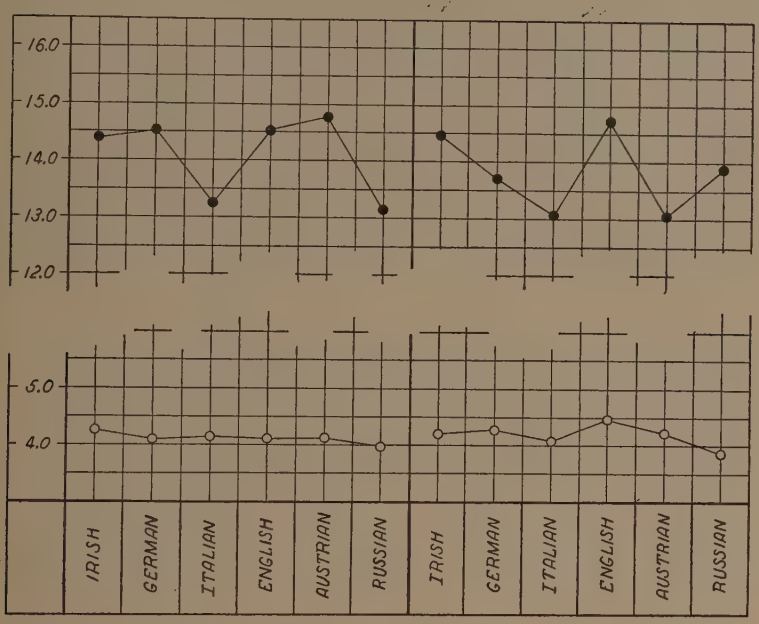

FIG. 6.—Comparison of relative variability (in terms of coefficients of variation) of body length (circles) and body weight (solid dots) in newborn infants of various nationalities.

4.3 per cent for girl infants. The coefficients of variation for body weight are from about 13.2 to about 14.8 per cent for boys and from about 13.2 to 14.5 per cent for girls. Thus it is clear that the variability of body weight is about three times as great at birth as that of body length. The left-hand side of the diagram gives the variabilities for girls, while the right-hand side represents those for boys. Clearly there is no large difference in the variability of the two sexes at birth. The coefficients for

length differ but slightly from nationality to nationality. Those for weight fluctuate widely.

These figures have shown that when we make allowance for the difference in the nature of two characters, weight and length, and in the order of magnitude of the measurements, the variability in birth weight is about three times as great as that in birth length. This is in itself an interesting biological result, which must be elucidated by further quantitative studies of masses of individuals with respect to growth and other phenomena. The findings become more suggestive for research on the manifold problems of mankind when we recall that the infants of the several nationalities considered differ more in body weight than in body length. Turning back to Figure 4, we note that differentiation from nationality to nationality is greater with respect to body weight than with respect to body length.[6] Thus differentiation from nationality to nationality is most prominent for the character that shows the highest variability within its own class.

One other illustration will make the usefulness of the measures of relative variability quite clear. The central panel of Figure 7 (p. 27) shows that in general the length or occipito-frontal diameter (solid dots) of the head of the newborn infant has a higher standard deviation than the breadth (or biparietal diameter). The upper panels show, however, that the average occipito-frontal diameter is greater than the biparietal in all nationalities studied. Since the occipito-frontal dimension is larger, it is reasonable to expect that it will have a larger absolute variability (standard deviation). When we correct for the average magnitudes of the two dimensions by expressing the standard deviations as percentages of their means (that is, as

[6] If we express these differences between nationalities on a percentage scale as described above, we find a maximum difference of 6.9 per cent of the body weight in the case of boys and 5.7 per cent of the body weight in the case of girls, in the comparison of Irish and Russian infants. For body length we find a maximum percentage difference of less than 2 per cent. From these maximum values the differences vary to practically zero in many of the comparisons.

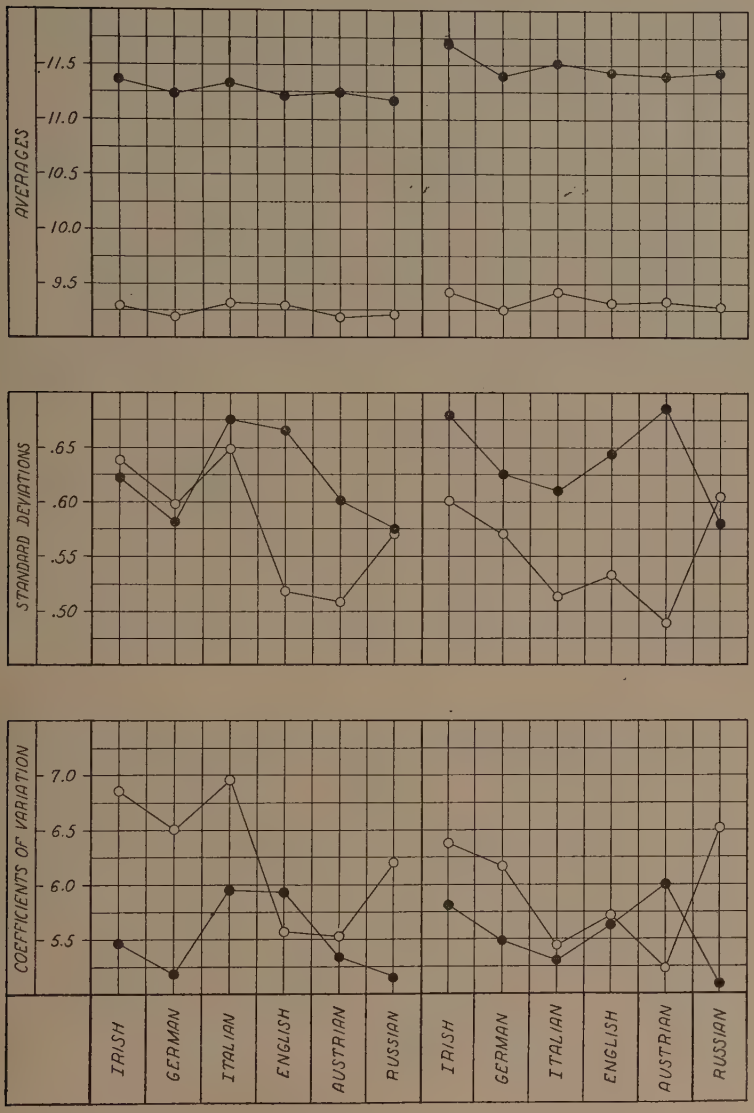

FIG. 7.—Constants for the length (occipito-frontal) and breadth (biparietal) of the head in newborn infants of various nationalities.

coefficients of variation), it appears from the figures in the lower panel that in general the variability of the breadth of the head is greater than that of the length. The results are reasonably consistent for boys (right side of the diagram) and for girls (left side of the diagram).

Specifically, the coefficients of variation of the biparietal dimension are of the order 5.2 to 7.0 per cent, whereas those of the occipito-frontal dimension are of the order 5.2 to 6.0. This result opens up a group of problems for further consideration. Is the difference in variability in the dimensions due to molding at birth, or does it represent the influence of some innate factor? A study of such series of measurements as are available for adults suggests that the latter is the case.

The powers of such simple constants as means, standard deviations, and coefficients of variation for yielding results of value in the field of the measurement of the characteristics of masses of men are far greater than can possibly be illustrated here, but the examples given will suffice, for we must now proceed to other kinds of measurements that are essential for the understanding of human phenomena of surpassing interest.

The Measurement of Interrelationship between the Characteristics of Man in the Mass

Our interest in man is not limited to the average size nor to the absolute or relative variability of individuals. We are perhaps even more deeply concerned in the measurement of the interdependencies between human characteristics.

A few illustrations will make quite clear the need of quantitative expression. We know that in general there is some relationship between many of the physical dimensions of the human body. Men who are taller than the average are usually above the average weight. Men who have long legs are apt to have long arms. Hair and eye color are so related that we expect to find certain combinations of these two characteristics, but not others.

If we are actually to measure the interrelationship between two characteristics of human beings, we can obtain accurate conceptions only through considering relatively large numbers of cases. This is true because if we dealt with one individual or with a very few individuals, we could, within limits, pick out materials with practically any combination of characteristics that we choose. Or if we drew our individuals at random and dealt with samples of only a very few cases each, we might by pure chance obtain a very different combination of characters each time. We must, therefore, in order to draw rigid and generally valid conclusions, work with such numbers of individuals that we may be reasonably certain that they will form a representative sample of human beings of the particular nationality, race, or social group with which we are concerned. For example, if we wish to know what relationship exists between the characteristics of those pairs of human individuals who elect to marry, we cannot obtain any satisfactory conception of the relationship by considering one individual pair only, no matter how accurately we know the couple. We wish to know whether pairs of individuals who marry are purely random samples of the general population of men and women or whether there is some relationship between their physical or mental characteristics.

All such relationships to be most useful should be measured on a universally comparable scale. The most desirable scale is one with a total range of unity, and so selected that if we should obtain a measure of zero on this scale, it will show that if we know the characteristic under consideration of the husband, we know nothing at all of the characteristic of the wife, while if we should obtain a measure of unity, it will show that knowing the characteristic of the husband, we will also know the characteristic of the wife.

There are doubtless certain characteristics for which measures of interrelationship between husbands and wives are zero. As far as we know, however, there are no characteristics

that are so definitely related in the case of husbands and wives that they give a measure of unity, that is, such a measure of similarity that, knowing the characteristic of one individual, we also know the characteristic of the other individual.

Thus, while the vast majority of marriages are between members of the same race, this is by no means invariably so. Marriages between Negroes and Whites, Indians and Negroes, Japanese and Malayans, and Caucasians and Chinese are known to occur in an appreciable number of cases. Thus, while a knowledge of the race of the husbands furnishes a considerable degree of presumption concerning the race of the wives, it by no means affords certain knowledge in regard to it. The correlation between the characteristics of husband and wife with respect to the race to which they belong will not, therefore, be perfect, or unity. We must, therefore, expect that measures of interrelationship between the characteristics of husbands and wives, if they exist at all, will be found to be less than unity.

Probably the greatest similarity between the characteristics of husbands and wives, other than that of race, is age at marriage. Notwithstanding conspicuous exceptions to the contrary, husbands and wives are apt to be of about the same relative age. By relative age, I mean to take account of the fact that men and women marry at somewhat different average age levels. Thus the average age of wives for all age classes of husbands will probably be less than that of their husbands.

The relationship between the age of bride and bridegroom at marriage may be illustrated by the statistics of 2,500 marriages abstracted from Chicago records by Lutz. The entries in Table 3 (p. 31) give the number of cases in which the parties had the ages indicated in the scales at the bottom and at the left. Inspection of the frequencies shows that while the age of the brides for any class of bridegrooms (except those extreme classes in which the numbers are very small) is highly variable and while a similar condition of variability is found in the age of the husbands for any particular age class of

TABLE 3

DISTRIBUTION OF AGES OF HUSBANDS AND WIVES AT MARRIAGE AS DETERMINED FROM 2,500 CHICAGO CERTIFICATES

AGE OF HUSBAND	AGE OF WIFE																TOTAL
	13–15	16–18	19–21	22–24	25–27	28–30	31–33	34–36	37–39	40–42	43–45	46–48	49–51	52–54	55–57	58–60	
64–66	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	1
61–63	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
58–60	...	...	...	2	...	...	...	...	...	2	...	1	1	1	1	2	10
55–57	...	...	...	...	...	...	...	...	...	2	2	...	1	...	2	...	7
52–54	...	...	1	...	...	3	1	2	1	2	3	4	1	1	1	...	20
49–51	...	...	...	2	1	2	...	4	1	3	2	4	4	2	1	...	26
46–48	...	...	...	1	3	3	3	2	4	5	3	2	2	...	...	...	28
43–45	...	...	...	4	2	5	6	6	6	5	6	2	...	1	...	...	43
40–42	...	1	3	7	10	8	4	9	10	8	1	...	2	...	...	...	63
37–39	...	1	2	12	16	15	9	8	15	...	6	3	1	1	...	...	89
34–36	...	2	13	26	29	23	21	11	3	5	4	...	1	1	...	...	139
31–33	...	3	21	35	48	34	20	7	4	4	...	...	...	...	...	...	176
28–30	...	14	74	117	100	52	16	3	4	2	...	...	...	...	...	...	382
25–27	...	59	217	197	101	20	3	1	1	...	...	...	...	...	...	...	599
22–24	...	76	334	169	32	4	4	1	...	...	...	...	...	...	...	...	620
19–21	1	113	147	25	5	3	...	...	...	...	...	...	...	...	...	...	294
16–18	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
Total	1	271	812	597	347	172	87	54	49	38	27	16	13	8	6	2	2500

brides, there is a marked tendency for the ages of the two parties to be interdependent. This is shown by the shift in the swarm of frequencies on the surface of the table as we pass from lower to higher ages on either of the two marginal scales.

Determining this relationship on a quantitative scale, ranging from 0 to 1, we find that it is measured by a coefficient of $r = +.75$. This shows that the relationship between the age of brides and grooms at marriage is about 75 per cent of perfect interdependence.

The mathematician can utilize the correlation coefficient as a basis for the computation for the line showing the mean ages of wives of different classes of husbands, or vice versa. Such lines and the equations upon which they are based are shown in Figure 8. In this figure the scale at the bottom represents the age of either husbands or wives at marriage. The position of any solid dot in relation to the scale at the left shows the mean age at marriage of husbands (upper series of points and fitted straight lines) or of wives (lower series of points and fitted straight lines) whose consorts had the ages shown on the scale along the lower margin of the figure. The straight lines traversing the somewhat irregular rows of dots represent the equations lettered on the figure. The fit of these theoretical lines is remarkably good except in the case of marriages at fifty years of age or older, when there are some irregularities.

At the beginning of this discussion of the age of men and women at marriage we noted the belief that women marry on the average at an earlier age than men. The difference between the position of the two series of means and the two fitted lines shows the average difference in the age of wives and husbands at each age of marriage of either men or women.

This simple illustration has been selected because familiarity with the relationship with which we have dealt will make the measurement of the magnitude more intelligible to those who are as yet unacquainted with the correlation coefficient. It also shows that we can pass at will from a measurement of interre-

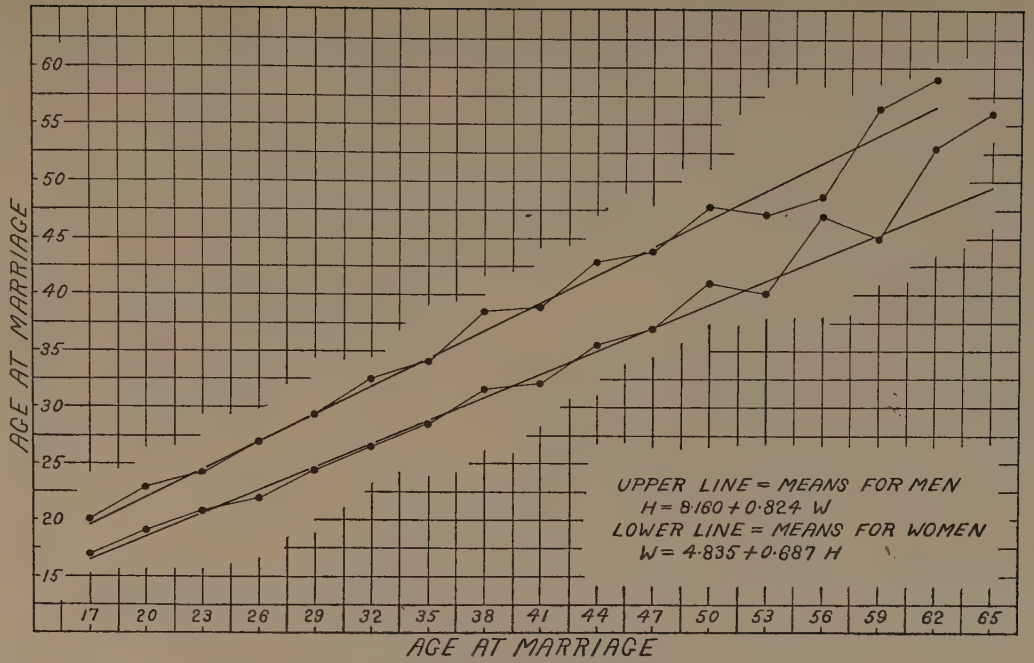

FIG. 8.—Mean values of age of husbands of wives of various ages and of age of wives of husbands of various ages and mathematically fitted lines in 2,500 Chicago marriages.

lationship in terms of the universally comparable scale of correlation to equations by which we may graduate the average ages of the wives of husbands of different ages or vice versa. For example, the equation shows that for each year of increase in the age of the bride, the husband will be on the average 0.82 year older, while for each year of increase in the age of the husband, the wife will on this average be 0.69 year older.

The expression of this relationship between the ages of husbands and wives at marriage in terms of a biometric constant is valuable for two reasons. First, it makes precise and quantitative, knowledge that before was vague and qualitative. It furnishes a constant that is available for direct comparison with other constants, for either the same character or for any other pair of characters. Second, it at once suggests other lines of inquiry and thus stimulates research.

For example, this tendency for individuals of like ages to marry presents an interesting problem when we pass from the consideration of individuals as such to groups of individuals. Some sociologist has stated that whereas the time of the marriage of men is determined largely by economic conditions, the time of the marriage of women is little affected by such conditions, and that the women of regions presenting quite different economic environments marry at about the same age.

Such an assertion can be easily tested by considering statistics for masses of individuals. For example, the various French departments differ materially in the conditions of life that they afford their inhabitants. Were the average time of marriage for the majority of women practically independent of these conditions, we should expect to find a high variability in the average age of men at marriage, but practically no variability in the average age of women at marriage. The means, standard deviations, and coefficients of variation for the French statistics as given in Table 4 (p. 35) show that in the French departments the women marry on the average 53.33 months, or about

4 years and 5 months, younger than the men. This is in reasonable accord with conditions as they prevail in other regions.

The results of greatest interest for our present discussion are the measurements of variability. Both the standard deviations, which furnish a measure of the variability in absolute terms, and the coefficients of variability, which correct for the difference in the mean ages of husbands and wives, are actually higher for the mean age of women at marriage than for the mean age of men at marriage. These differences appear to be enough larger than their probable errors to be considered trustworthy.

TABLE 4

MEANS OF THE MEAN AGE AT MARRIAGE AND VARIABILITIES OF THE MEAN AGE AT MARRIAGE OF MEN AND WOMEN IN THE FRENCH DEPARTMENTS

	MEAN	STANDARD DEVIATION	COEFFICIENTS OF VARIATION
Men	337.76±0.80	11.03±.56	3.26±.17
Women	284.43±1.03	14.25±.73	5.01±.26
Difference	−53.33±0.64	+3.22±.92	+1.75±.31

Certainly such results do not support the statements that have been made. The women vary from department to department in their mean age at marriage about as the men do. If there be a significant difference between the two sexes, the age of the women at marriage is actually more variable than that of the men. Since this variability must be due to variations in the economic and social conditions prevailing in these departments, the results tend to show that the time of marriage of women is more closely determined by these conditions than is that of men.

The problem can be solved in another way. If the mean age of women at marriage be independent of economic and social

conditions, while the mean age of men at marriage is closely dependent on such conditions, we should find that the mean age of the women of the several departments at marriage is not related to that of the men. We find, however, that the correlation coefficient measuring the relationship between them is $r = .781 \pm .028$. This is an actually closer degree of interrelationship than that found for the ages of individual husbands and wives!

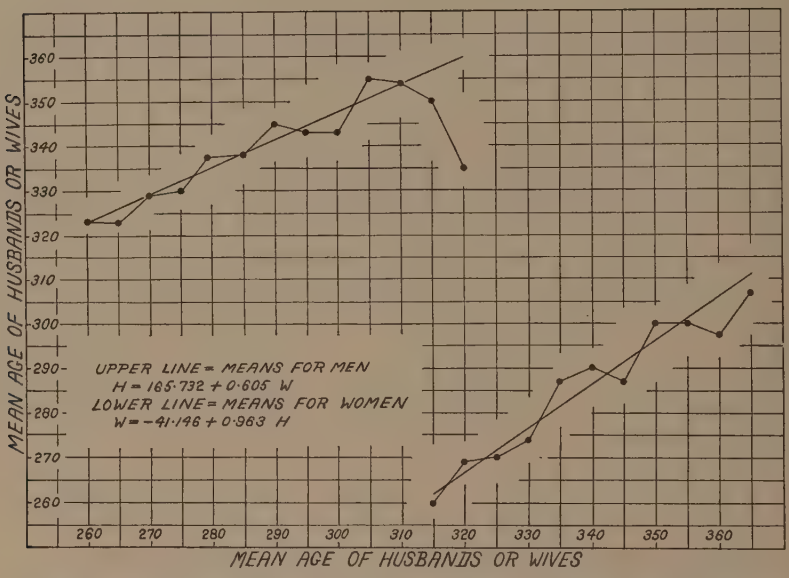

FIG. 9.—Mean values of age of wives of husbands of various mean ages, and mean values of age of husbands of wives of various mean ages in the French departments, with fitted straight lines.

From the foregoing constants we may derive an equation showing the rate at which the mean age of women at marriage increases as we pass from department to department in which the men marry, on the average, earlier, to those in which they marry later in life. Similarly we may write an equation showing the rate at which the age of men at marriage is postponed as we pass from departments in which the average age of

women at marriage is low, to those in which it is relatively high.

The equations are given and represented with the actual means for husbands of wives of a given average age and for wives of husbands of a given average age (as shown by the scale at the bottom) on Figure 9. These equations show that for each month that the average age of men at marriage is postponed, the mean age of women at marriage will be postponed by about the same amount (0.96 months).

These "regression coefficients" (of 0.963 and 0.605) have their probable error. Hence we must not lay too much weight on the actual value, but merely state that in round numbers the mean age of women at marriage is advanced or postponed by economic and social conditions by approximately the same or by an even greater period of time than is that of men.

Age is only one of several characteristics for which there is a marked and definitely measurable interrelationship between characteristics of husbands and wives. Such relationships are particularly interesting in view of the theories that were held before the time when the making of precise measures of interrelationship was possible. The assertion has often been made that men and women of unlike characteristics tend to marry. Perhaps the making of this statement was in part due to the assumption that each individual desired to supplement his own qualities by those somewhat different in his companion. Probably, however, a major factor determining the belief in a tendency for individuals of different characteristics to marry was the conspicuousness of those pairs that were very much unlike. A very tall husband and very short wife present a contrast frequently noted. When the opposite combination is found, comment is even more apt to be made. The conspicuousness of these individual instances has led those who have depended upon general observation and personal judgment rather than upon exact quantitative measurement of phenomena to hold that individuals of highly unlike character-

istics are attracted to each other. When we consider the relationship in terms of actual measurements of masses of individuals, we find, however, that for stature and for certain other measurable physical characteristics, there is a marked degree of what Karl Pearson has called "assortative mating" in human individuals.

Turning back to Figure 2, which has already served for a discussion of the relative stature of British husbands and wives, we detect a distinct tendency for the swarm of dots to shift upward as one passes from the lower to the upper end of the scale for male stature. In other words, there is a tendency for the wives of tall men to be themselves taller than the women who marry husbands of smaller stature.

Expressing this relationship on our correlation scale, we find that it is measured by a coefficient of $r = + .280 \pm .019$. While the coefficient is small as compared with the $r = 1.000$, which would denote a perfect correlation between the two variables, it is very large as compared with the probable error that furnishes a criterion of its trustworthiness and therefore shows that there is a clearly marked tendency, in the long run, for husbands and wives to be similar in stature.

This relationship may be most convincingly shown by plotting the mean statures of the wives of husbands of different heights, or the mean statures of husbands of wives of different heights. The average statures of the wives are shown in the upper section, and the average statures of the husbands in the lower section of Figure 10. The equations that graduate or smooth the series of means are given on the diagrams. The second terms of the right-hand side of these equations determine the slopes of the straight lines. They show that for each deviation for the husband of one inch from the average stature of all husbands of the sample, the wives of husbands of this grade of stature will show a deviation of 0.248 inch from the average stature of wives. Conversely, husbands of wives of any

given grade of stature will, on the average, differ from the average stature of all husbands by $\frac{317}{1000}th$ of the amount by which their wives differ from the average stature of all wives measured.

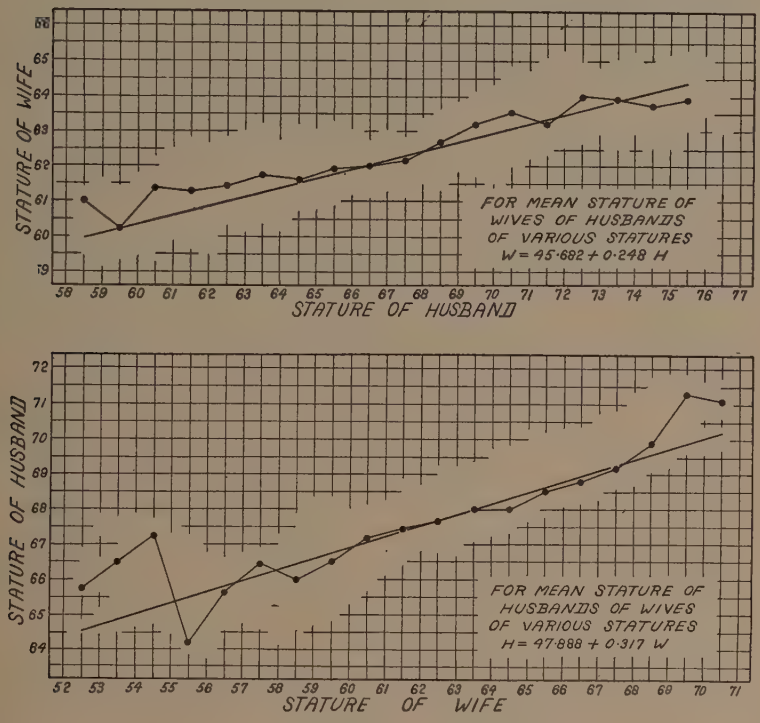
STATURE OF WIFE
FOR MEAN STATURE OF WIVES OF HUSBANDS OF VARIOUS STATURES
W = 45·682 + 0·248 H
STATURE OF HUSBAND
STATURE OF HUSBAND
FOR MEAN STATURE OF HUSBANDS OF WIVES OF VARIOUS STATURES
H = 97·888 + 0·317 W
STATURE OF WIFE

FIG. 10.—Mean values of stature of wives of husbands (upper figure) of various statures and mean values of stature of husbands of wives (lower figure) of various statures.

Our confidence in the reality of these interrelationships will be strengthened by examining the coefficients for some other physical character. Table 5 gives the correlation for the possible combinations of stature, span, and forearm in the series studied by Pearson and Lee. All of these coefficients are positive. While they are small, they are far larger than their prob-

able errors and show a clearly marked tendency for individuals of like characteristics to marry.

That this relationship is not universal for physical characteristics is shown by the fact that in groups of individuals studied in Holland, little assortative mating was found for such a characteristic as length and breadth of head and cephalic index.[7]

TABLE 5

MEASUREMENT OF THE SIMILARITY OF PHYSICAL DIMENSIONS OF HUSBANDS AND WIVES IN TERMS OF THE CORRELATION COEFFICIENT

	HUSBAND'S CHARACTER	WIFE'S CHARACTER	ASSORTIVE MATING (CORRELATION AND PROBABLE ERROR)
Direct correlations	Stature	Stature	.2804±.0189
	Span	Span	.1989±.0204
	Forearm	Forearm	.1977±.0205
Cross correlations	Stature	Span	.1820±.0201
	Stature	Forearm	.1403±.0204
	Span	Stature	.2023±.0199
	Span	Forearm	.1533±.0203
	Forearm	Stature	.1784±.0201
	Forearm	Span	.1545±.0203

I have utilized assortative mating as an illustration of the measurement of interrelationship because the similarity of the ages of brides and grooms is familiar, and because the problem is interesting in itself. Such measures of interrelationship may be applied to innumerable problems involving the degree of interdependence of two characteristics that are associated in the same individual or in two individuals who for any logical reason are related to each other. In the following sections we shall consider a few examples of the measurement of the inter-

[7] J. Arthur Harris and Albert Govaerts. Note on assortative mating in man with respect to head size and head form. Amer. Nat., 56:381-383. 1922.

relationship between the magnitudes of the parts of the human body.

The Measurement of the Interrelationship of Physical Characters in Man

We may advantageously select as a first illustration the measurement of a relationship that is so intimate that its existence can be detected in a qualitative way by unaided observation. Notwithstanding all of the variations in body build, taller individuals may be recognized by any acute observer to be heavier. The degree of relationship is such that its magnitude can be determined with a fair degree of exactness from relatively few data. For example, Figure 11 (p. 42) shows the mean body weight in kilograms of a series comprising 136 men and 103 women, selected in part because it contains but few individuals, and in part because these particular cases are required later. While the mean weights are scattered with considerable irregularity about the straight lines given by the equations, there can be no doubt that for purposes of a first approximation the straight lines give a fairly satisfactory graduation of the results. The correlations in these cases are:

$$\text{for men,} \quad r = .5725 \pm .0389,$$
$$\text{for women,} \quad r = .3257 \pm .0594.$$

If such a relationship as that between stature and weight be considered on the basis of extensive series of data, much closer agreement between the theoretical line and the observed means will be secured. This statement is substantiated by the actual calculations of the average body weights of 2,501 English convicts measured by Goring.[8]

Table 6 (p. 43) shows the number (column 2) of convicts of various statures (column 1) and their average body weights (column 3). The average body weights of these convicts as calculated from an equation involving the correlation coefficient and lettered on Figure 12 are given in the fourth column. The differences between the actual and the calculated averages are

[8] Sir Charles Goring. The English convict. H. M. Stationery Office, London. 1913.

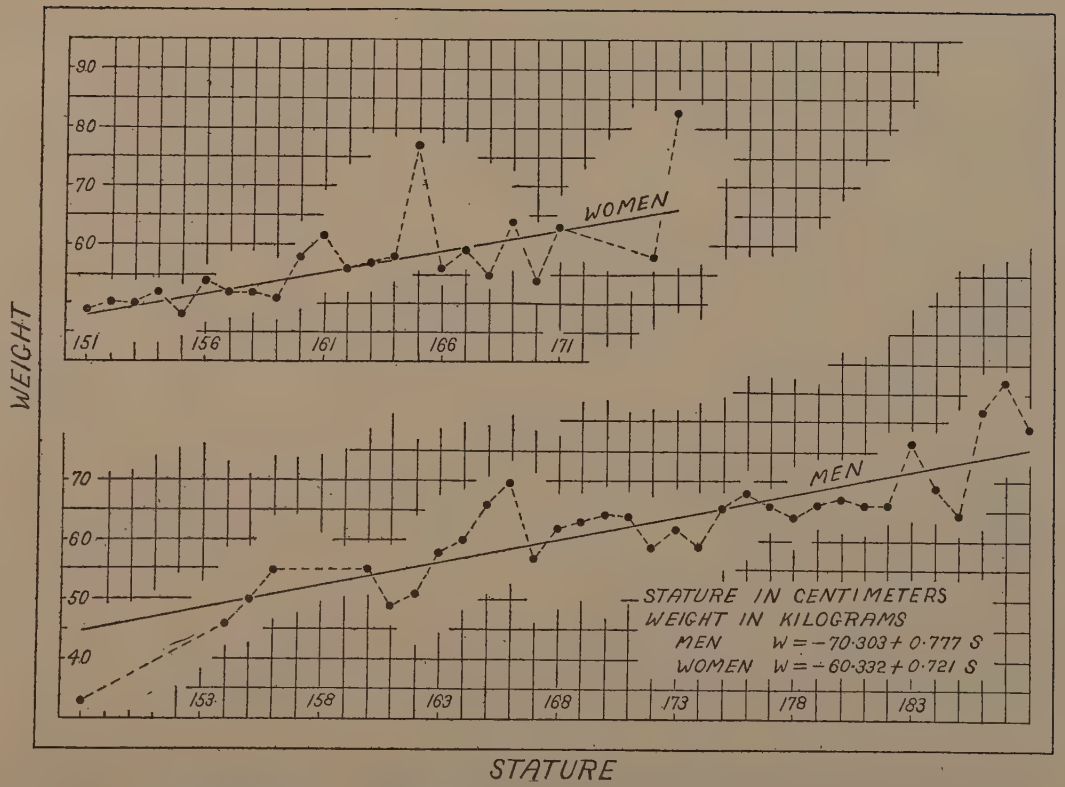

FIG. 11.—Relationship between weight and stature in men (lower figure) and women (upper figure) whose oxygen consumption and daily heat production were determined at the Carnegie Nutrition Laboratory.

TABLE 6

COMPARISON OF AVERAGE BODY WEIGHT AND CALCULATED AVERAGE BODY WEIGHT IN 2,501 ENGLISH MALE CONVICTS STUDIED BY GORING

STATURE	NUMBER OF CASES	ACTUAL AVERAGE BODY WEIGHT	THEORETICAL AVERAGE BODY WEIGHT	DIFFERENCE	PERCENTAGE DIFFERENCE
54.5	1	85.00	104.26	—19.26	18.47
55.5	2	90.00	107.78	—17.78	16.49
56.5	1	105.00	111.29	— 6.29	5.65
57.5	4	110.00	114.81	— 4.81	4.19
58.5	3	118.33	118.33	+ 0.00	0.00
59.5	23	121.96	121.84	+ 0.11	0.09
60.5	59	124.49	125.36	— 0.87	0.70
61.5	118	128.98	128.88	+ 0.10	0.08
62.5	220	133.00	132.40	+ 0.60	0.45
63.5	285	135.81	135.92	— 0.11	0.08
64.5	327	139.37	139.43	— 0.06	0.04
65.5	386	143.11	142.95	+ 0.16	0.11
66.5	346	146.19	146.47	— 0.28	0.19
67.5	289	152.51	149.99	+ 2.52	1.68
68.5	220	151.36	153.50	— 2.14	1.39
69.5	116	155.69	157.02	— 1.33	0.85
70.5	58	160.17	160.54	— 0.37	0.23
71.5	22	161.36	164.06	— 2.69	1.64
72.5	11	165.91	167.57	— 1.66	0.99
73.5	7	176.43	171.09	+ 5.34	3.12
74.5	2	185.00	174.61	+10.39	5.95
75.5	...	.....	178.13	....	....
76.5	...	.....	181.64	....	....
77.5	1	195.00	185.16	+ 9.84	5.31

shown in pounds in the fifth column and are expressed as percentages of the statures given by the equation in the final column of the table.

The theoretical or smoothest averages are represented by the fitted line in Figure 12 (p. 44), while the actual average weights are shown by the positions of the solid dots. The the-

oretical line and the actual means are in almost exact agreement except for the very short and the very tall men, who are so few in number that the averages are irregular, as they have been found to be for all classes in Figure 11 (p. 42), where the total number of individuals is small.

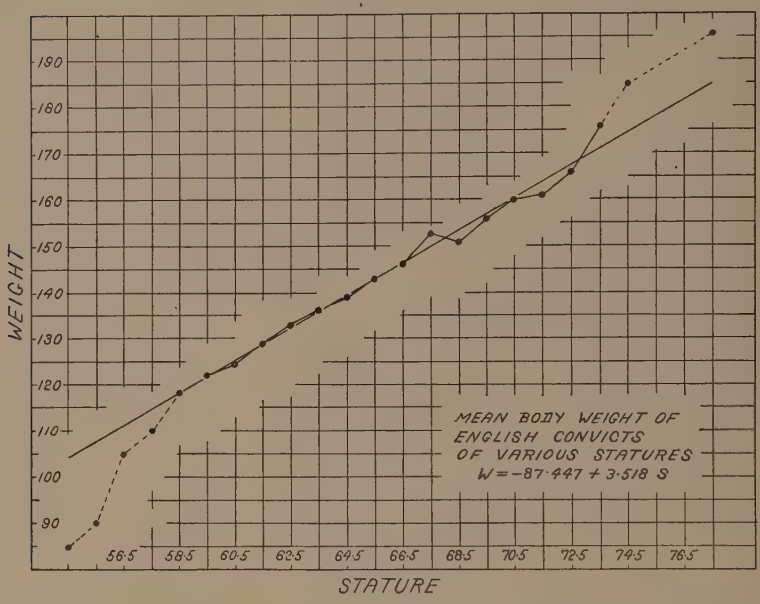

Fig. 12.—Relationship between stature and body weight in 2,501 English convicts studied by Goring.

If we omit the 4 lower and the 4 upper classes of stature, which contain only 11 of the 2,501 convicts, we find that the average difference per individual between the weights given by the equation and those actually found is less than 1 per cent in 13 of the 15 comparisons. The close agreement of the observed and the calculated results when large numbers of measurements are considered, and the irregularity that is seen at the ends of the lines where but few individuals (those who are very short and those who are very tall) are available, is the very

point that we desire to emphasize when we urge the value of the methods of the investigation of man in the mass.

One of the best tests of the validity of any method is the consistency of the results obtained from its application to wholly independent series of measurements. Discrepancies between the constants may be due either to inadequacy of method or to actual differences between the series considered. It will be interesting, therefore, to examine the correlations that have been found by different observers for the relationship between stature and body weight at birth in the human infant, and to compare these results with those obtained for stature and weight in adult individuals. A few correlations between sitting height and body weight in mature individuals are added for comparison. Table 7 gives the results for the newborn infant while Table 8 gives the constants for adults. The original data on which all these constants are based have been cited by Harris and Benedict,[9] with the exception of those for the Air Service candidates, which were published by Cripps, Greenwood, and Newbold.[10]

All of these measures of interrelationship of body length, or stature, and body weight are of a substantial order of magnitude. All are very large as compared with their probable errors. The consistency of the values for both infants and adults strengthens confidence in their significance.

It appears, however, that the coefficients for adults are lower than those for infants. The correlation between body length and body weight becomes smaller as we grow from infancy to maturity. There is little doubt that variations in the extent to which individuals store fat during the period of adult life accounts to some extent for this difference in correlation.

The measurement of the relationship between stature and

[9] J. Arthur Harris and F. G. Benedict. A biometric study of basal metabolism in man. Pub. Carn. Inst. Wash., 279:i-vi, 1-266. Washington, 1919.

[10] L. D. Cripps, M. Greenwood, and E. M. Newbold. A biometric study of the interrelations of "vital capacity," stature, stem length, and weight in a sample of healthy male adults. Biometrika, 14:316-336. 1923.

TABLE 7

CORRELATIONS BETWEEN BODY LENGTH AND BODY WEIGHT IN NEWBORN INFANTS

SERIES	NUMBER	CORRELATION
Nutrition Laboratory		
Males	51	.770±.038
Females	43	.864±.026
British Association		
Males	451	.665±.018
Females	466	.539±.022
Lambeth Hospital		
Males	1,000	.644±.012
Females	1,000	.622±.013
Dr. Taylor's series		
Males	120	.668±.034
Females	122	.749±.027

TABLE 8

CORRELATIONS BETWEEN STATURE AND BODY WEIGHT AND BETWEEN SITTING HEIGHT AND BODY WEIGHT IN ADULT INDIVIDUALS

SERIES OF MEASUREMENTS	NUMBER	CORRELATION BETWEEN STATURE AND WEIGHT	CORRELATION BETWEEN SITTING HEIGHT AND WEIGHT
Harvard men, Castle	1,000	.544±.015	.....
Cambridge men, Pearson	1,000	.486±.016	.....
Cambridge women, Pearson	160	.721±.026	.....
British convicts, Goring	2,501	.555±.009	.....
British Air Service candidates			
All candidates	1,238	.547±.013	.528±.014
Fit candidates	950	.544±.015	.540±.016

body weight has been selected as a first illustration because of the familiarity of this interdependence. When we turn to less familiar magnitudes of the body the difficulties of forming an unaided judgment concerning the actual amount of interrelationship are insuperable except by means of mathematical constants. For example, few would venture an opinion as to whether stature and the length of one of the anterior digits are more or less closely correlated than stature and body weight, or whether stature and the length of the forearm are more or less closely interrelated than stature and body weight or stature and finger length. Since fully suitable figures for all three characters are not available for one series of individuals, we will satisfy ourselves by taking independent sets of measurements for adult British males.

Using measurements of stature and forearm of 1,050 English fathers and of their 1,164 adult sons [11] and MacDonell's [12] measurements of stature and the length of the left middle finger in 3,000 male convicts from New Scotland Yard, we find:

Characters	Correlation
Stature and forearm, fathers	.752 ± .009
Stature and forearm, sons	.758 ± .008
Stature and finger	.661 ± .007

These results show, first, that in adult individuals the relationship between stature and the length of the finger is less intimate than that between stature and the length of the forearm, and, second, that both of these relationships for linear dimensions of the body are somewhat larger than those for stature and body weight as given in Tables 7 and 8.

The rigidity with which the interrelationships between stature and length of forearm and between stature and length of finger hold is shown by the orderliness of the distributions of

[11] K. Pearson and Alice Lee. On the laws of inheritance in man. I. Inheritance of physical characters. Biometrika, 2:357-462. 1903.

[12] W. R. MacDonell. On criminal anthropometry and the identification of criminals. Biometrika, 1:177-227. 1901.

the means of the lengths of these two organs for various grades of stature, as represented in Figure 13.

At the extremes of stature (where the number of individuals is very few) the averages of the lengths of forearm and of the lengths of finger show material deviations from the fitted

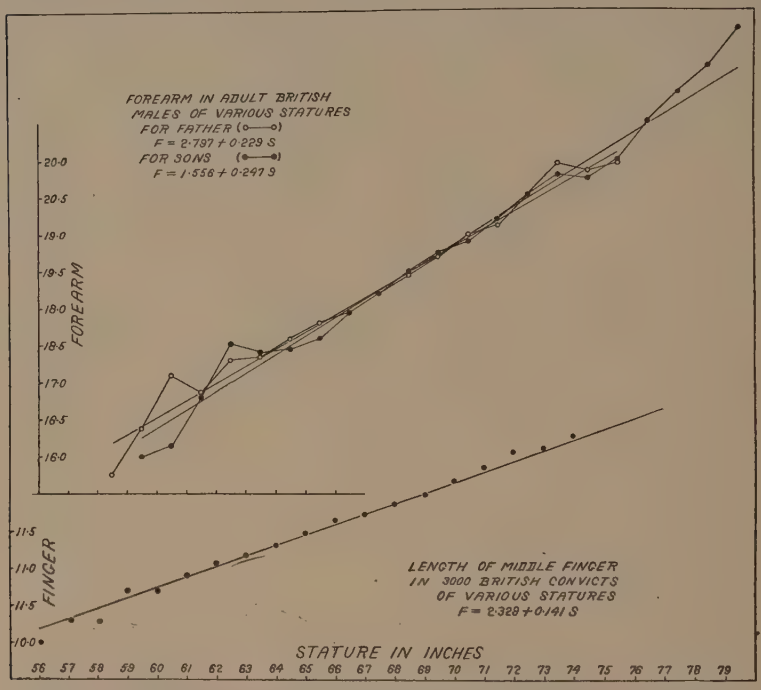

FIG. 13.—Relationship between stature and length of forearm and between stature and length of finger in man.

straight lines. When the numbers of measurements are reasonably large the agreement between the line given by the equation and the actual means is close enough to satisfy the critical worker in the so-called exact sciences of chemistry, physics, or astronomy. The close superimposition of the lines for fathers and sons lends weight to the conclusion that we are dealing with a highly orderly phenomenon. When human individuals

are considered in large numbers we can deal with the relationships between their bodily dimensions with mathematical precision.

The fact that the measures of body size treated in these illustrations have shown roughly the same degree of interdepend-

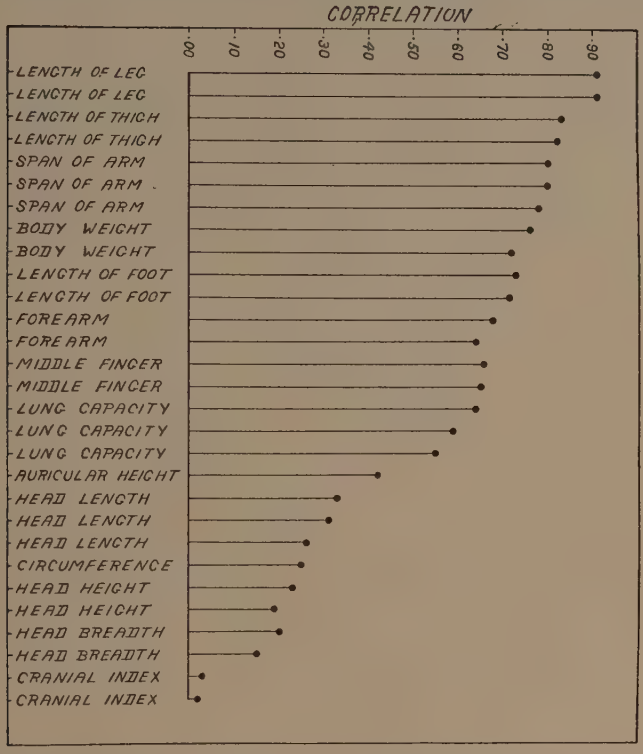

FIG. 14.—Magnitudes of coefficients of correlation between stature and various other bodily dimensions in man.

ence or correlation must not lead to the unwarranted conclusion that all parts of the body are equally interrelated. It may be readily seen that the different dimensions of the body are interdependent in varying degrees by comparing the correlation coefficients between stature and a series of other dimensions of the body.

All of the relationships represented in Figure 14 (p. 49) are between stature and some other character as indicated on the legends below the solid dots, which represent the magnitude of the correlation on the scale at the left. In a number of instances two determinations based on quite different series of measurements are included in order to show the close concordance of the results. These coefficients show in what varying degrees the several dimensions of the body are interrelated. Two of these correlations—the measures of interrelationship between stature and the two dimensions, length and breadth of the head—will engage our attention later.

In our investigation of the interdependence of the size of the various parts of the human body we are not limited to a consideration of the relationships between absolute dimensions. In some cases we may use special formulae that show the relationship between one dimension and the relative size of another dimension. As an illustration let us take the problem of the relationship between stature and the length of the appendages in man. This has been considered under a somewhat different guise by anthropologists. They have devoted considerable attention to the relationship between stature and sitting height or stem length, as it has sometimes been called. Rather extensive measurements made on school children are available from the studies by Boas and Wissler,[13] which have been recalculated in a form suitable for present purposes.[14]

During the school period the child is growing. Figure 15 shows that in the series of Worcester boys that we shall use by way of illustration, sitting height, leg length (as approximately given by the differences between stature and sitting height), and total stature are, on the average, increasing with a high degree of regularity with age. For this reason we must deal with groups of boys of approximately the same age in order not to

[13] F. Boas and C. Wissler. Statistics of growth. Ann. Rept. U. S. Com. Ed., 1904: 28-132. 1905.

[14] J. Arthur Harris. On the relationship between stature and the length of the appendages in man. Amer. Nat., 53:254-271. 1924.

have our results too much modified by differences between the individuals due to age. An age range of two years is perhaps allowable.

The coefficients given in the third column of Table 9 show that there is a high correlation between stature and sitting

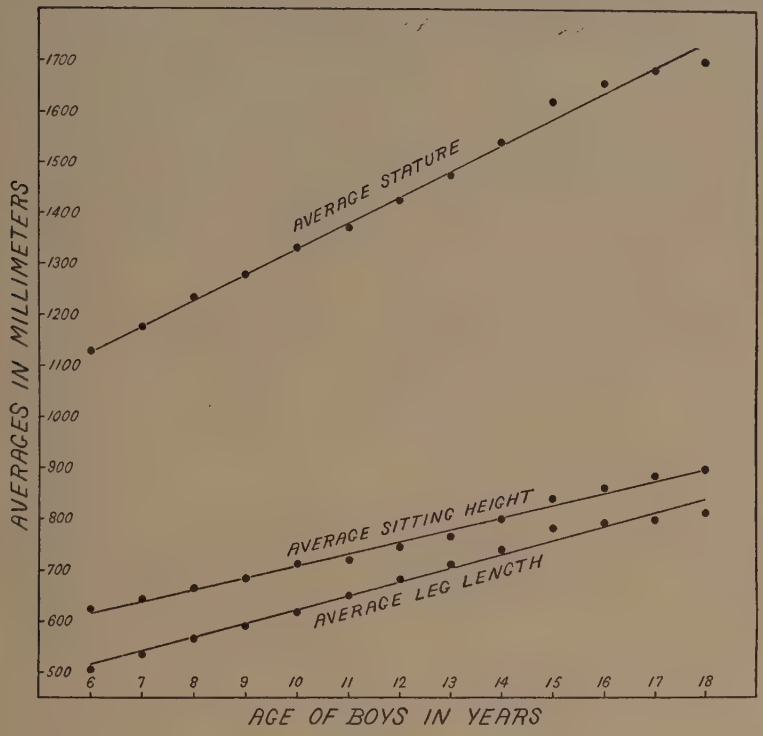

FIG. 15.—Relationship between stature, sitting height, and leg length and age in boys.

height. If we plot the mean sitting height of a series of individuals against the total stature, beautifully regular results are obtained. Figure 16 represents the average sitting height in millimeters of series of Worcester boys of various ages. The actual means are shown by solid dots. The equations that graduate or smooth these means are lettered on the diagrams. The agree-

ment between the straight lines and the actual means is very close indeed. This shows at once that when we deal with large numbers of individuals the proportions of the body are, on the average, very constant. Sitting height increases in a very orderly manner with total stature.

Such results fail, however, to bring out all of the relationships that merit our attention. Taller individuals must, on the

TABLE 9

CORRELATION BETWEEN STATURE AND SITTING HEIGHT AND CORRELATIONS BETWEEN STATURE AND THE DEVIATIONS OF SITTING HEIGHT AND LEG LENGTH FROM THEIR PROBABLE VALUES

AGE OF BOYS	NUMBER OF BOYS	CORRELATION BETWEEN STATURE AND SITTING HEIGHT	CORRELATION BETWEEN STATURE AND DEVIATION OF SITTING HEIGHT FROM ITS PROBABLE VALUE	CORRELATION BETWEEN STATURE AND DEVIATION OF LEG LENGTH FROM ITS PROBABLE VALUE
6 and 7	248	+.82±.01	—.28±.04	+.28±.04
8 and 9	244	+.83±.01	—.29±.04	+.29±.04
10 and 11	235	+.80±.02	—.42±.04	+.42±.04
12 and 13	276	+.88±.01	—.33±.04	+.33±.04
14 and 15	268	+.93±.01	—.14±.04	+.14±.04
16 and 17	187	+.82±.02	—.20±.05	+.20±.05

average, have greater sitting height, because sitting height is one of the components of total stature, which represents merely the sum of head, trunk length, and leg length. It seems remarkable that anthropologists have been satisfied to limit their attention to the mere measurement of the relationship between two things that are so obviously interdependent.

One of the things that we should know is whether tall individuals owe their greater stature primarily to long legs or to long trunks. In individual cases, either of these lengths may be the determining factor. As students of man in the mass, we de-

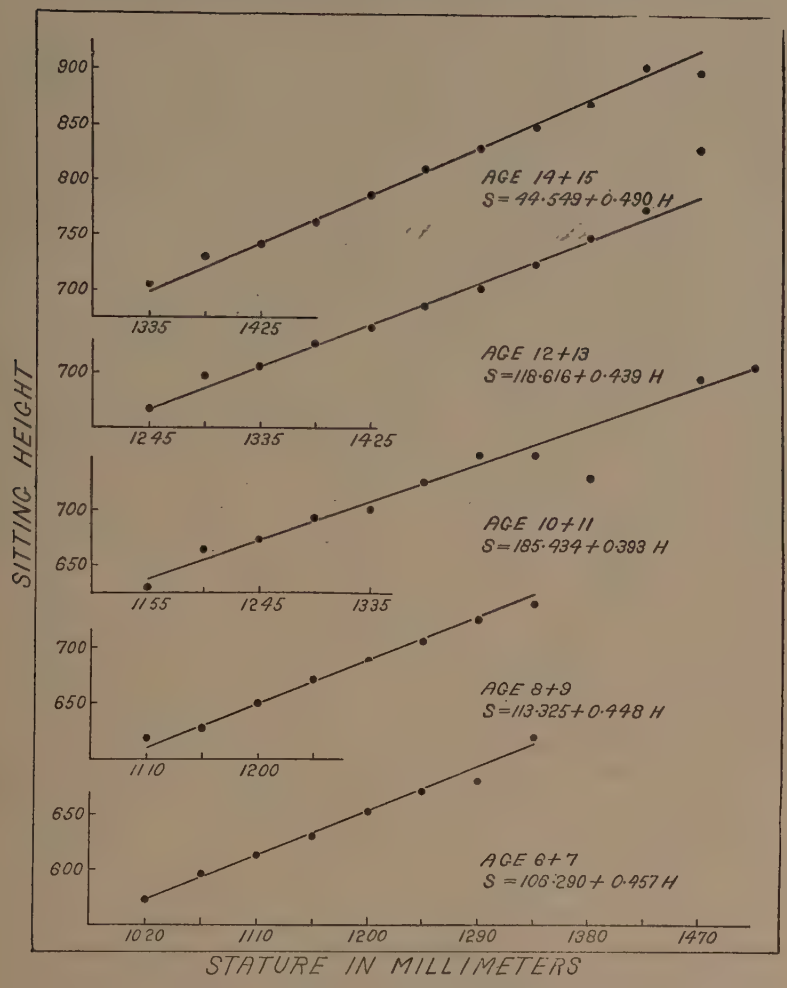

Fig. 16.—Relationship between sitting height and stature (both in millimeters) in Worcester boys.

sire to know which in the long run is the primary determining factor. This problem may be investigated by ascertaining whether tall individuals have relatively greater sitting height than short individuals. The results may be expressed in terms of a correlation coefficient that shows the relationship between

the total stature and the deviation of sitting height from its probable value, i.e., from the value that it would have if sitting height were a constant proportion of stature throughout the entire range of total stature.[15] The fourth column of Table 9 (p. 52) shows these coefficients. They are negative throughout, thus showing that as total stature increases the relative contribution of sitting height to total stature becomes smaller.

One of the characteristics of this particular kind of correlation coefficient is that if it shows a negative correlation of a given amount between total stature and stem length, it will show a positive correlation of equal magnitude between total stature and the deviation of the remaining part of stature from its probable value. This remaining part of the stature is essentially leg length. The coefficients in the final column of Table 9 are of the same numerical magnitude as those for stem length, but are positive in sign.

Now it is quite possible to determine equations showing the change in the relative stem length, or in the relative leg length, associated with variation in total stature.[16] A series of equations of this kind corresponding to the coefficients in columns 4 and 5 of Table 9 appears in Figure 17. The upper panel shows the relation between stature and the deviation of sitting height from its probable value. The lower panel shows the relationship for stature and the deviation of leg length from its probable value, i.e., the value that leg length should have where it is directly proportional to body stature for all individuals of the series. The solid dots showing the actual means are distributed with some irregularity about the lines that represent the equations lettered on the diagrams. This is inevitable when we deal with series no larger than the present. A few of the more extreme deviations, which were based on a wholly inadequate

[15] J. Arthur Harris. The correlation between a variable and the deviation of a dependent variable from its probable value. Biometrika, 6:438-443. 1909.

[16] J. Arthur Harris. Further illustration of the applicability of a coefficient measuring the correlation between a variable and the deviation of a dependent variable from its probable value. Genetics, 3:328-352. 1918.

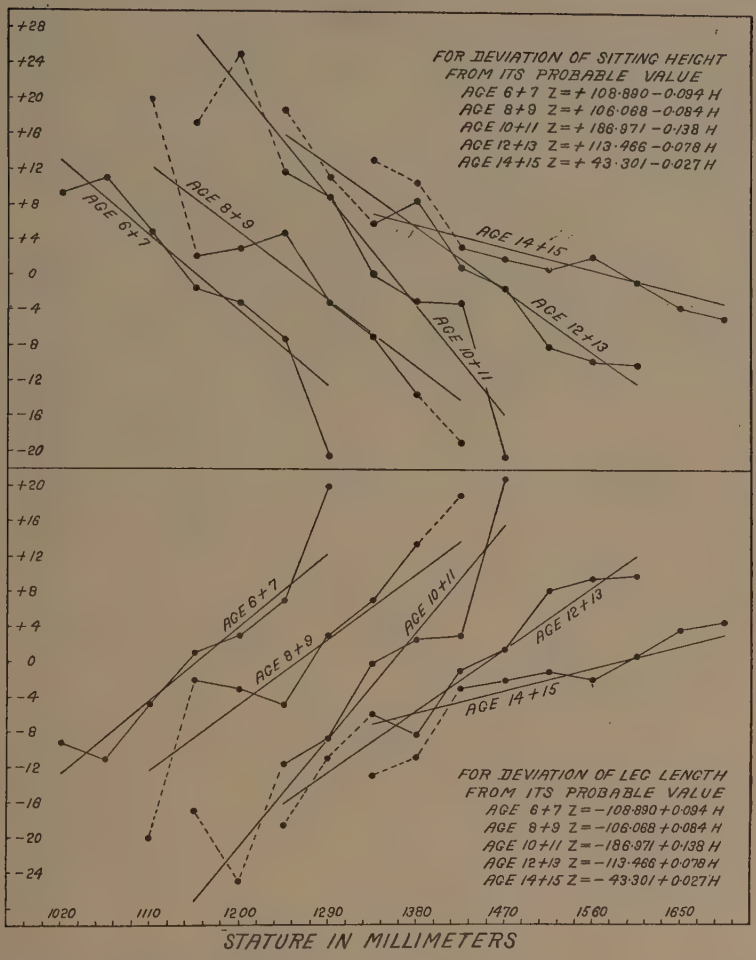

Fig. 17.—Relationships between stature and relative sitting height and leg length in boys. For explanation see text.

number of measurements, have been omitted. Notwithstanding the irregularities, the results show clearly that the relative sitting height decreases, while the relative leg length increases rapidly, as we pass from children of low to children of higher stature. Thus it is clear that the length of the legs is really the

important factor determining stature. Taller individuals are tall because they have both long legs and long trunks. The leg length is, however, the more important of the two in determining stature in groups as a whole.

The Measurement of the Relationship between Physiological and Physical Characteristics in Man

In the preceding sections we have limited our attention to the measurement of the interrelationship between physical characteristics in human individuals. The methods may be applied equally well to the measurement of the interrelationship between a physical characteristic and a physiological function.

As research in human and comparative physiology has progressed, we have more and more been forced to conclude that the human body, like the bodies of other animals and plants, is in many ways a machine. In this highly organized structure chemical reactions take place much as they do in the laboratory. While the processes as they occur in the living organism are highly complicated in nature, there seems to be no essential difference from those that take place in the inorganic world.

The human body must depend for its activities upon energy derived from the burning of recently ingested food, of reserve fat, or of the tissues of the body itself. This oxidation of food or of other substances results in heat production. Such heat production can be measured by placing a human individual inside a chamber containing water between its double walls. The heat radiated from the body raises the temperature of the water, thus permitting the measurement of the total amount of heat produced during the experimental period. While this process is accurate, the manipulation is difficult. Extensive experimentation has shown that the heat production of the human individual may be calculated from his oxygen consumption and his carbon-dioxide production with a satisfactory degree of accuracy.

The amount of heat produced by the human body depends

largely upon muscular activity, but even in a state of complete muscular repose combustion is continually taking place. This is called the *basal metabolism* and it may be measured in terms of calories of heat production for twenty-four hours or for any other unit of time. The amount required for active work of various kinds must be added to the basal amount, which varies

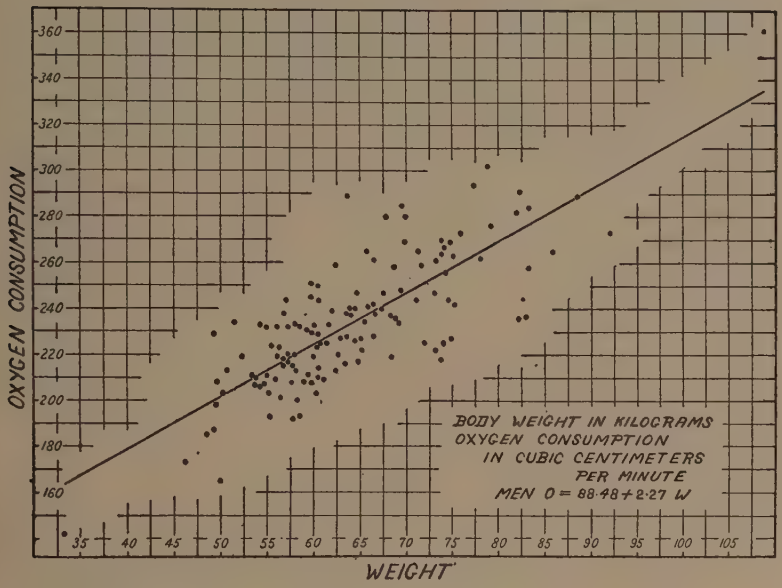

Fig. 18.—Relationship between oxygen consumption and body weight in men as determined at the Carnegie Nutrition Laboratory.

from individual to individual. Thus studies of basal metabolism are of fundamental importance in determining the minimum food requirements of human individuals.

On theoretical grounds it seems reasonable to assume that the amount of oxidation of substances will be in some measure proportional to the size of the individual. Inspection of Figure 18 shows this to be the case. The solid dots represent the body weights and the daily oxygen consumption of 136 men studied under very closely controlled conditions at the Nutrition Lab-

oratory of the Carnegie Institution of Washington, at Boston, Massachusetts. Quite clearly the oxygen consumption increases with some regularity as body weight becomes greater. Similar results might be shown for the carbon-dioxide production of

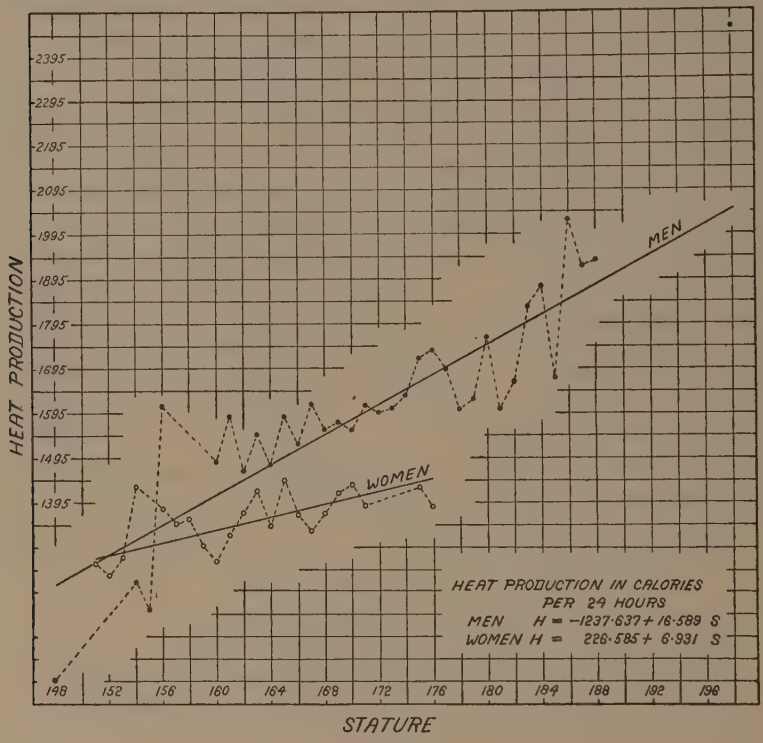

Fig. 19.—Relationship between daily heat production and stature in men and women as determined at the Carnegie Nutrition Laboratory.

these men. Calculating the mean calories of heat production per twenty-four hours from the actual measurement of oxygen consumption and carbon-dioxide production, we have the relationships between body height and heat production shown in Figure 19 above and between body stature and oxygen consumption shown in Figure 20. These figures show the averages for 136 men and 103 women. It is quite clear that there

is an intimate relationship between both of these measures of body size and daily heat production. Determining these relationships in terms of correlation, we have the coefficients set forth in Table 10 (p. 60). These constants merit rather intensive study. We note that for men the correlations between stature and oxygen consumption, carbon-dioxide production and

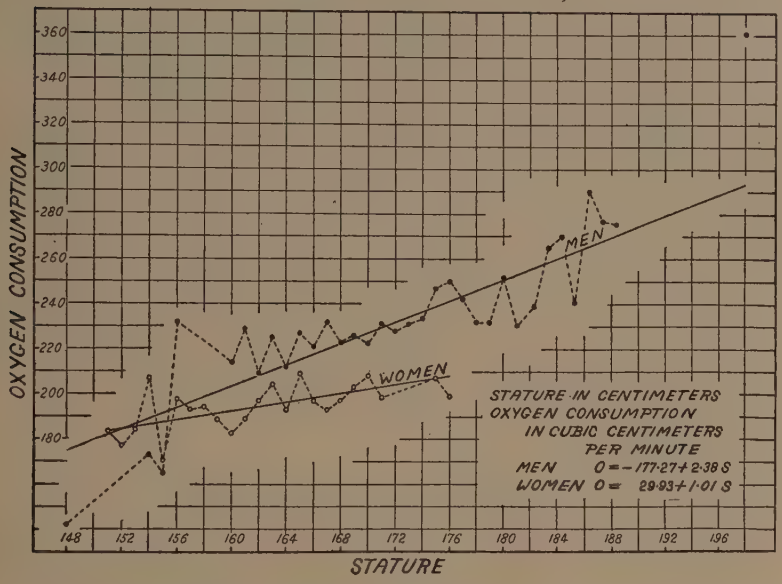

FIG. 20.—Relationship between oxygen consumption and stature in men and women as determined at the Carnegie Nutrition Laboratory.

calories of heat production, are of about the order $r = 0.60$. The coefficients for body weight and oxygen consumption, carbon-dioxide production and total heat production, are distinctly larger values. Finally, the correlations between the computed body surfaces of these individuals (a measure of size that takes into account both stature and weight) are larger in each case than in any of the preceding values. It is interesting to note that in all cases the correlations for men are higher than those for women. The explanation of this difference must be sought in future experimentation.

TABLE 10

COMPARISON OF CORRELATIONS BETWEEN VARIOUS DIMENSIONS OF THE BODY AND MEASURES OF HUMAN BASAL METABOLISM

BODY MEASUREMENT AND NATURE OF COMPARISON	MEASURE OF METABOLISM		
	Oxygen Consumption	Carbon-Dioxide Production	Heat Production in Calories
Stature			
Men	+.6140±.0360	+.5882±.0380	+.6149±.0360
Women	+.2331±.0628	+.2575±.0627	+.2318±.0629
Difference	—.3809±.0724	—.3307±.0733	—.3831±.0725
Body weight			
Men	+.7955±.0212	+.7575±.0247	+.7960±.0212
Women	+.5950±.0429	+.6266±.0408	+.6092±.0418
Difference	—.2005±.0479	—.1309±.0477	—.1869±.0469
Body surface			
Men	+.8196±.0190	+.7884±.0229	+.8196+.0190
Women	+.5972±.0428	+.6357±.0399	+.6111±.0416
Difference	—.2224±.0468	—.1527±.0460	—.2085±.0457
Difference between correlation for stature and weight*			
Men	+.1815±.0418	+.1693±.0453	+.1811±.0418
Women	+.3619±.0760	+.3691±.0748	+.3774±.0755
Difference between correlation for stature and body surface†			
Men	+.2056±.0407	+.2002±.0444	+.2047±.0407
Women	+.3641±.0760	+.3782±.0743	+.3793±.0754
Difference between correlation for weight and body surface‡			
Men	+.0241±.0285	+.0309±.0337	+.0236±.0285
Women	+.0022±.0606	+.0091±.0571	+.0019±.0590

* (Correlation for weight) less (correlation for stature).
† (Correlation for surface) less (correlation for stature).
‡ (Correlation for surface) less (correlation for weight).

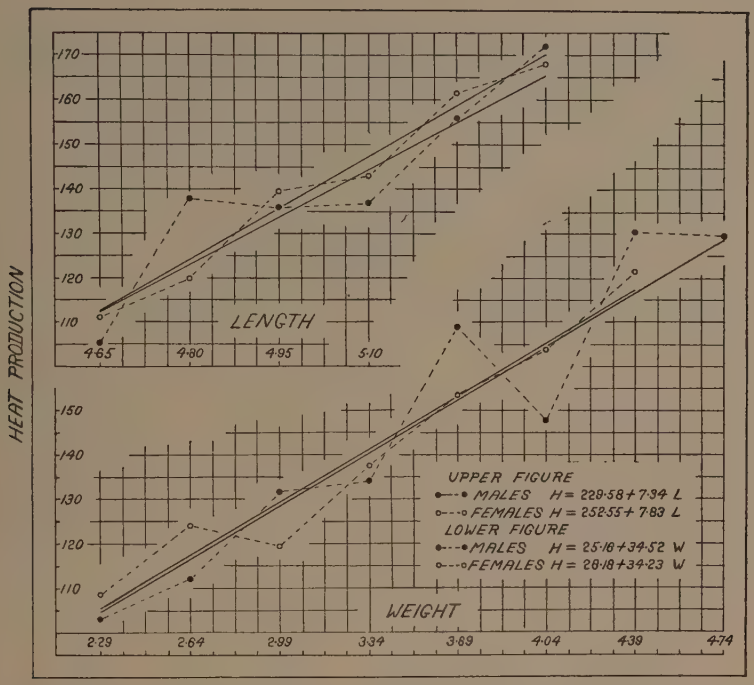

FIG. 21.—Relationship between daily heat production and weight and length in newborn infants measured at the Carnegie Nutrition Laboratory.

That these relationships between body weight and daily heat production and between stature and daily heat production are not limited to adult life is shown by Figure 21. These figures are based on only 51 male and 43 female newborn infants. The mean heat productions are, therefore, distributed with considerable irregularity about the straight lines, which are given by the equations lettered on the diagrams. The correlations for the newborn infants are as follows:

	CORRELATION BETWEEN STATURE AND HEAT PRODUCTION	CORRELATION BETWEEN WEIGHT AND HEAT PRODUCTION
Boy babies	.6191 ± .0582	.7520 ± .0411
Girl babies	.7426 ± .0461	.8081 ± .0357

The coefficients of correlation for infants are of about the same order of magnitude as those for adults. Again it appears that the correlations between weight and heat production are slightly higher than that between stature, or body length, and heat production.

In some cases it is difficult to distinguish between measurements that should be classed as physical and those that should be considered physiological. Among these are such characteristics as lung capacity and strength. The entries in Table 11 [17]

TABLE 11

CORRELATIONS BETWEEN MEASUREMENTS ON OXFORD STUDENTS OF VARIOUS AGES

AGE	STATURE AND WEIGHT	STATURE AND LUNG CAPACITY	WEIGHT AND LUNG CAPACITY	LUNG CAPACITY AND STRENGTH OF PULL
18	.50±.04	.44±.05	.55±.04	.44±.05
19	.63±.02	.65±.02	.62±.02	.40±.03
20	.68±.03	.55±.03	.52±.03	.37±.04
21	.76±.02	.64±.03	.66±.03	.32±.05
22	.72±.03	.59±.04	.62±.04	.31±.06
Average	.66	.57	.59	.37

show that stature and lung capacity and weight and lung capacity are about as closely interrelated as stature and weight, but that the correlation between lung capacity and strength of pull is of a materially lower value.

A further illustration of interrelationship of characteristics that are on the borderline of the fields of structure and function is supplied by the series of measurements for the newborn infant of various nationalities already cited. The order of birth

[17] E. Schuster. First results from the Oxford Anthropometric Laboratory. Biometrika, 8:40-51. 1911.

and the order of the pregnancy,[18] as well as the age of both of the parents, are matters of record. The magnitudes of the correlations between these four time variables and the length and weight of the infants at birth are represented in Figure 22 (p. 64). Here the legends below the eight figures show the time variable with which body weight (left side of diagram) and body length (right side of diagram) are correlated. The transverse bars over the legends denote zero on the correlation scale. The position of the circles (correlation coefficients for girls) and of solid dots (correlation coefficients for boys) show on the scale at the left the magnitude of the correlations for Austrian (A), German (G), English (E), Irish (I), Italian (It), and Russian (R) infants.

With only a single exception the correlations between age of father, age of mother, pregnancy order, and birth order, on the one hand, and the weight of the child, on the other, are positive in sign. While the correlations are low, many of the coefficients for both age of parents [19] and birth order and pregnancy order,[20] on the one hand, and weight and length on the other, have been shown to be statistically trustworthy. The coefficients measuring the relationship between these variables (age of parents, birth order, and pregnancy order) and the length of the child are of a lower order of magnitude and are in a number of cases slightly negative in sign.

The results as a whole can leave no doubt as to the existence of a definite correlation between the time variables considered and the length and weight of the infant at birth. Both of these measures of body size increase with the age of the parents and

[18] By birth order we mean merely the serial number of the child, first, second, third, etc. By pregnancy order we mean the serial number of the pregnancy. These two numbers are not always the same, since pregnancy does not always result in the birth of a living child. Thus for a given infant the pregnancy order might be 3, 4, or 5, etc., while the birth order might be 3.

[19] J. Arthur Harris. On correlation between age of parents and length and weight of the newborn infant. Proc. Soc. Exp. Biol. Med., 23:801-805. 1926.

[20] J. Arthur Harris. Relationship between pregnancy order and birth order and length and weight of newborn infants. Proc. Soc. Exp. Biol. Med., 23:806-808. 1926.

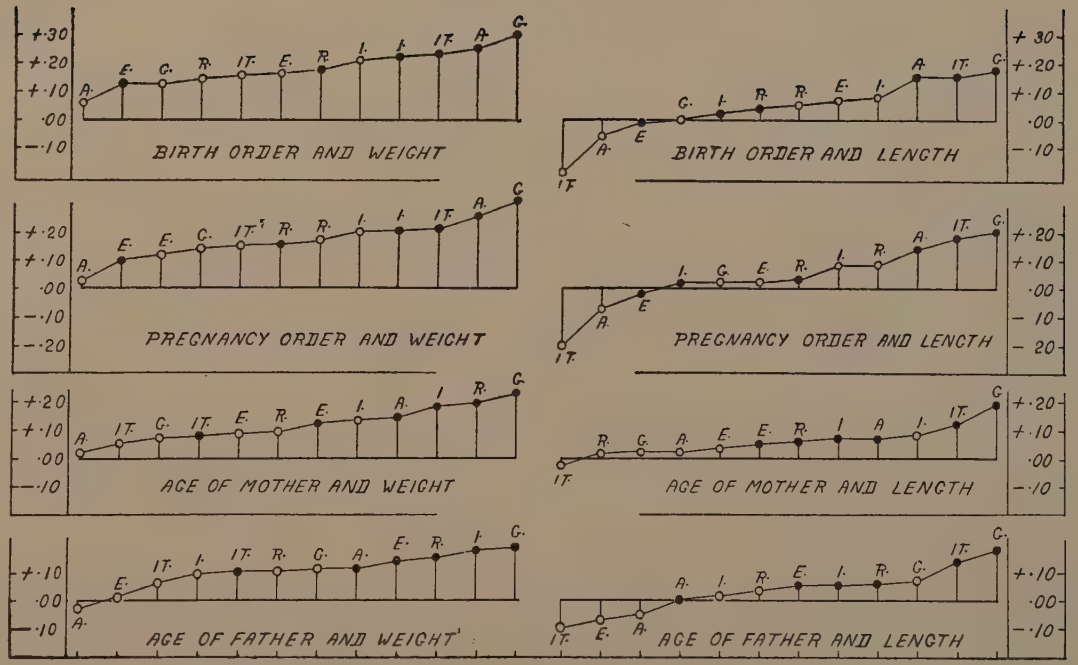
BIRTH ORDER AND WEIGHT
BIRTH ORDER AND LENGTH
PREGNANCY ORDER AND WEIGHT
PREGNANCY ORDER AND LENGTH
AGE OF MOTHER AND WEIGHT
AGE OF MOTHER AND LENGTH
AGE OF FATHER AND WEIGHT
AGE OF FATHER AND LENGTH

FIG. 22.—Relationship between the birth weight and birth length of the newborn infant and the age of its parents, its birth order, and its pregnancy order.

with the number of the pregnancy and the birth. The interpretation of these definitely established facts must await the results of other investigations, some of which are now in progress.[21]

The citation of constants might be multiplied, but our purpose is not to treat in detail the problems of the interrelationship between physical characteristics and physiological functions in man, but merely to illustrate the kind of quantitative results that may be secured. For our present purposes it is sufficient to note that the methods of measurement of man in the mass permit the accurate expression of relationships of the greatest importance between physical and physiological characteristics. Future progress in our knowledge of certain phases of human nutrition must depend in no small degree upon the application of measures of this kind to extensive series of accurate experimental data.

The Measurement of Partial Interrelationships

We may see on a moment's consideration that if we have measurements of three characters, say, x, y, and z, on a number of individuals, and if each of the pairs of measurements, x and y, x and z, and y and z, are correlated, it will be impossible to determine without special investigation whether the interrelationship between any two of these measurements is wholly independent of the relationship of each of the two measurements to the third.

[21] As a word of caution to those inexperienced in biometric work, we must note that the demonstration of a statistically significant correlation between two variables does not necessarily indicate a causal relationship between them. The difficulty encountered in certain cases is best seen in the relationship between the ages of the parents and the characteristics of the child. The ages of the parents are closely correlated. Thus if there be a definite relationship between the age of either of the parents and the dimensions of the child, there must be some correlation between the age of the other parent and the characteristics of the child due solely to the correlation between the two parents themselves. Nor can we conclude that there is a direct causal relationship between the age of the mother and the measurable characteristics of the child. Pregnancy order and birth order are correlated with the age of the mother, and from the raw values of the correlations alone it is difficult to determine whether age or pregnancy or birth order is the proximally causal variable influencing the size of the infant. Extensive accessory investigations in this field will be necessary to clear up some of these problems.

This somewhat complex problem may be clarified by a specific example. It may be shown that there is a measurable interrelationship between the length and breadth of the head. While men are often classified as to their head form into "broad headed" and "long headed," and into various intermediate classes, it is found that when numbers of individuals are considered, those who have heads that are broader than the average also have heads that are longer than the average. For example, MacDonell [22] found the correlation between the length and breadth of the head in 3,000 criminals and in 1,000 Cambridge students to be:

	Correlation
Criminals	.4016 ± .0103
Students	.3448 ± .0188

It is also known that both head length and head breadth are in some degree related to stature. Taller men have, on the average, both longer and broader heads than shorter men. Thus for the 1,000 Cambridge students mentioned above the correlations are:

	Correlation
Stature and head length	.2816 ± .0198
Stature and head breadth	.1529 ± .0209

The question must arise: Is it possible that this relationship between head length and head breadth may be merely the resultant of the relationship between each of these dimensions and stature? That this is not the case is rendered probable by the fact that the correlations between stature and the length and the breadth of the head are both lower than that between the two dimensions of the head.

Provision for the solution of this problem is made by a formula for the determination of the partial correlation between head length and head breadth. In determining the partial correlation we strip off the amount of the correlation between

[22] W. R. MacDonell. On criminal anthropometry and the identification of criminals. Biometrika, 1:177-227. 1901.

these two cephalic dimensions that is due to their dependence on stature. The gross and the partial correlations for the two dimensions of the head in the Cambridge students are:

Gross correlation	.3448 ± .0188
Partial correlation.....	.3182 ± .0192

Thus it appears quite clear that the relationship between the two dimensions of the head is largely independent of stature.

One further illustration will make clear the power of this method of quantitative analysis. We learned from the constants of Table 10 (p. 60) that oxygen consumption, carbon-dioxide production, and daily heat production are correlated with both stature and body weight. The correlations of these physiological measurements with weight are higher than those with stature. From Figure 11 we have seen that in the same series of individuals there is a medium ($r_{sw} = .5725$ for men and $r_{sw} = .3257$ for women) correlation between stature and body weight. One might infer that the relationship between stature and gaseous exchange and heat production is merely the resultant of the relationships between body weight and the physiological measures on the one hand and body stature on the other. The plausibility of this suggestion is apparent when we consider that the total heat production might be proportional to the body mass.

The question may be answered by determining the partial correlations between each of the physical characters and daily heat production for constant values of the other character. It is quite possible to compute partial correlations involving age as well as stature or body weight.

The constants are laid side by side in Table 12. These show that the values of the coefficients measuring the relationship between a physical character and daily heat production may be increased when correction is made for age (that is, when the partial correlation for constant age is determined), but that the correlation for heat production with each of the physical characters is greatly reduced when correction is made for

the others by means of the partial correlation method. The correlations are in no case reduced to zero. Thus it appears that both stature and weight have an independent influence on the daily heat production of the human individual.

In the study of man in the mass the possibilities of the partial correlation method are almost unlimited.

TABLE 12

COMPARISON OF GROSS AND PARTIAL CORRELATIONS MEASURING THE RELATIONSHIP BETWEEN STATURE AND BODY WEIGHT ON THE ONE HAND AND DAILY HEAT PRODUCTION OF HUMAN INDIVIDUALS ON THE OTHER

	Stature and Daily Heat Production			
	Gross Correlation	Correlation Corrected for Age	Correlation Corrected for Weight	Correlation Corrected for Age and Weight
Men	.6149±.0360	.6129±.0361	.3207±.0519	.2899±.0530
Women ...	.2318±.0629	.2700±.0616	.0445±.0663	.0850±.0660
	Body Weight and Daily Heat Production			
	Gross Correlation	Correlation Corrected for Age	Correlation Corrected for Stature	Correlation Corrected for Age and Stature
Men	.7960±.0212	.8384±.0172	.6867±.0306	.7510±.0252
Women ...	.6092±.0418	.7117±.0328	.5803±.0441	.6866±.0351

THE MEASUREMENT OF THE RELATIONSHIP BETWEEN NON-MEASUREABLE CHARACTERS

The characters of men and women hitherto considered have been directly and quantitatively measurable. Many of the most conspicuous and most certainly differential of the characteristics of human individuals cannot be actually measured, although they can be described with such definiteness that they constitute valid criteria for distinguishing between individuals.

Perhaps the most familiar examples of this kind are eye color and hair color. Casual observation shows us that there is some relationship between hair and eye color in human beings. Certain combinations of hair and eye color are frequent; others are rare.

TABLE 13

COMBINATIONS OF HAIR AND EYE COLOR IN 4,235 MALE INMATES OF SCOTTISH ASYLUMS

EYE COLOR	HAIR COLOR				TOTAL
	Red	Fair	Medium	Dark	
Light	37	175	1345	346	1903
	29.6	123.6	1133.3	616.5	
	+7.3	+51.4	+211.7	−270.5	
Medium	20	77	788	497	1382
	21.5	89.7	823.0	447.7	
	−1.5	−12.7	−35.0	+49.3	
Dark	9	23	389	529	950
	14.8	61.6	565.7	307.8	
	−5.8	−38.7	−176.7	+221.2	
Total	66	275	2,522	1,372	4,235

The upper figures in Table 13 above show the frequencies of various combinations of hair and eye color for 4,235 men who were inmates of Scottish asylums.[23] If the relationship between hair and eye color were perfect, we should expect to find only one color of hair associated with a given color of eye. If, on the other hand, the two characters were wholly unrelated, we should expect to find the two characteristics combined in a purely random manner. Neither of these conditions is realized. The second set of figures shows the number of individuals that we should expect if the colors were combined at

[23] J. F. Tocher. The anthropometric characteristics of the inmates of asylums in Scotland. Biometrika, 5:289-300. 1907.

random. The third set of figures is provided with signs that show whether the actual numbers are larger or smaller than those that are to be expected as a result of chance distribution alone.

TABLE 14

COMBINATIONS OF HAIR AND EYE COLOR IN 4,235 MALE INMATES OF SCOTTISH ASYLUMS, EACH REDUCED TO TWO CLASSES

EYE COLOR	HAIR COLOR		TOTAL
	Light	Dark	
Light	2,442	843	3,285
	2,220.8	1,064.2	
	+221.2	−221.2	
Dark	421	529	950
	642.2	307.8	
	−221.2	+221.2	
Total	2,863	1,372	4,235

Inspection of these differences shows that red, fair, and medium hair occur more frequently in association with light eyes, and that dark hair is found more often in association with medium and dark eyes than would be expected if the association of the two were purely random. Similarly, the occurrence of dark hair in association with light eyes and of red, fair, or medium hair with medium or dark eyes is less frequent than we should expect if there were not some relationship between the nature or quantity of pigment in eyes and hair.

The association between the pigmentation of the two regions of the body in which differences may be most readily observed is more clearly shown by combining light and medium eye color into one class to be considered "light" as contrasted with the "dark" class, and by combining red, fair, and medium hair color into one class to be designated as "light" when contrasted with "dark," as shown in Table 14 above. Here there is a vast excess of "light" and "light" and of "dark"

and "dark" combinations, and a corresponding deficiency in the frequencies of the combinations of unlike colors.

Now this represents a numerical presentation of facts of which we are vaguely conscious from observation. But our knowledge need not remain so indefinite. Such relationships as were shown in Table 13 may be expressed on a scale comparable with that of the correlation coefficient. The results of a number of determinations of this interrelationship made by Pearson [24] are shown below in Table 15. These furnish *quantitative* measures of the intensity of a relationship concerning which our previous conceptions have been merely qualitative. The explanation of the differences in the intensities of these interrelationships must await further research.

TABLE 15

CONTINGENCY COEFFICIENTS MEASURING THE RELATIONSHIP BETWEEN HAIR AND EYE COLOR

POPULATION	CONTINGENCY COEFFICIENT	SOURCE OF DATA
Male asylum inmates	.3039	J. F. Tocher
Female asylum inmates	.2994	J. F. Tocher
Adult Scottish population	.3673	J. F. Tocher
Scottish children	.3802	J. F. Tocher
Swedish conscripts	.2495	G. Retzius
Prussian children	.2714	R. Virchow
Italian conscripts	.3091	R. Livi
Jewish children	.3381	R. Virchow
Baden conscripts	.3540	O. Ammon
British schoolboys	.4203	K. Pearson

THE MEASUREMENT OF THE RELATIONSHIP BETWEEN THE CHARACTERISTICS OF DIFFERENT INDIVIDUALS

Consideration of the interrelationship between the various physical dimensions of the human body, and between the phy-

[24] K. Pearson. On the correlation between hair color and eye color in man. Biometrika, 3:459-462. 1904.

sical dimensions and the physiological functions of the body, has so dominated the preceding pages that the reader may, for the moment, have lost sight of the possibilities of the measurement of the interrelationship between the characteristics of different individuals.

That the measurement of the interrelationship between the characteristics of two different individuals is quite possible whenever it may contribute to our knowledge of mankind has already been shown by an illustration of the correlations between the physical measurements of husbands and wives. All that is necessary is that the two individuals who are to be compared be associated for some logical reason. Such pairs are furnished by parents and their children, by grandparents and their grandchildren, by uncles and aunts and their nephews or nieces, by brothers and sisters, and by cousins. It is of the greatest interest to determine on a quantitative scale how closely similar parents and their children are, and to extend the same kind of measurements to other blood relatives.

As an illustration of the exactness with which the relationship between the physical characteristics of blood relatives may be measured for man in the mass we will take the case of "parental inheritance." Figure 23 (p. 73) shows the relation between the statures of British parents and their children as studied by Karl Pearson and Alice Lee.[25] The statures of the fathers or mothers are shown on the scale at the bottom of the diagram. The average statures of their adult sons or daughters are shown by the position of the solid dots (sons) and circles (daughters) on the scale at the left. The equations that graduate or smooth these mean values must pass through the intersections of the means of the statures of parent and child. The amount of separation of the lines showing the position of the average stature of the two parents on the axis of abscissae and

[25] K. Pearson and Alice Lee. On the laws of inheritance in man. I. Inheritance of physical characters. Biometrika, 2:358-462. 1903.

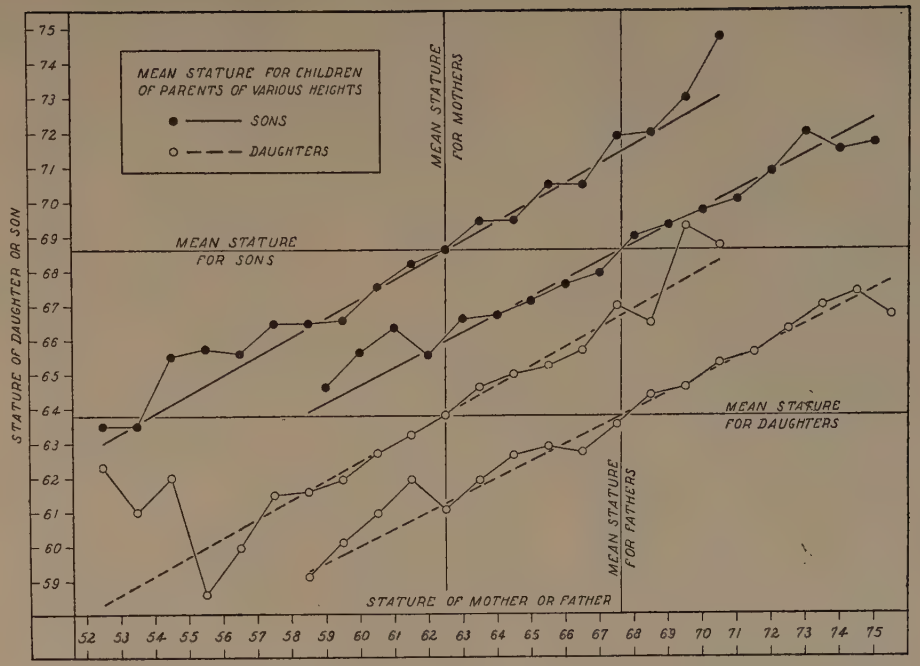

FIG. 23.—Relationship between the stature of sons and daughters and the stature of their parents as determined by Pearson and Lee.

of the sons and daughters on the axis of ordinates shows the extent to which men and women are differentiated in stature.

There are certain places near the ends of the series where the mean statures of the second generation deviate considerably from the straight lines. Taking the results as a whole there can be no doubt that a straight line represents reasonably well the shift in the average stature of (adult) children associated with variation in the statures of their parents. The correlation coefficients upon which the equations shown by the lines in this diagram are based are given in Table 16.

TABLE 16

COEFFICIENTS OF PARENTAL INHERITANCE DETERMINED BY PEARSON AND LEE

RELATIVES	CORRELATION
Father and son	.514±.015
Father and daughter	.510±.013
Mother and son	.494±.016
Mother and daughter	.507±.014

It was Francis Galton who first pointed out that as we pass back in time, there is attenuation of interrelationship between the characteristics of children and their ancestors. Thus, the interrelationship between the characteristics of the children and those of the parents will be more intimate or intense than that between the characteristics of children and grandparents, and still more so than that between children and great grandparents. It is upon relations of this kind that Francis Galton and Karl Pearson founded their law of ancestral inheritance. Little has been heard of this law in recent years because of the intense interest in other methods of studying inheritance. The time will probably come, however, when biologists will return to a more thoughtful consideration of these mathematical relations.

It will be quite clear that a knowledge of the physical char-

acteristics of the parents can never enable us to predict exactly the bodily dimensions of the child. Even the additional knowledge of the characteristics of the grandparents leaves this an impossibility in the individual instance. But if we devote our attention to man in the mass, we can know with a high degree of precision what the average characteristics of the offspring of any given combination of ancestry will be.

Since the periods of classical culture, and even from the periods of primitive culture, men have believed that children resemble their parents. Many familiar phrases attest this belief in the similarity of parents and children. It has remained for Galton and Pearson to express the amount of the interrelationship in quantitative terms.

IV. SUMMARY

In the foregoing pages we have considered some of the simpler methods and given fragmentary samples of the more elementary results of those who have sought to make the measurement of individuals contribute to our understanding of man in the mass.

I am fully aware that man's interest in man is highly personal. The greatest interest of men and women will not be mankind, which is made up of countless millions of human beings, but will be centered in the relatively few human individuals whom they know. It is altogether natural that in the affairs of everyday life it will be the fellow human beings with whom men and women come into contact who will make the strongest appeal to personal interest and sympathy. This is, and presumably always will be, reflected in art and literature and in daily conduct.

Notwithstanding this fact, we have seen that by the mathematical description and analysis of the measurements of masses of individuals we may learn far more of mankind than Pope or any of his successors, until recent times, could have dared to hope. The possibilities of such methods for the investigation of

the most highly organized and the most interesting of all the members of the animal kingdom are boundless. Sound and dependable knowledge of mankind can be gained by these means and by no others.

In speaking thus with enthusiasm of the possibilities of the measurement of man in the mass I am not urging the abandonment of interest in human individuals as such. All that is personally most worth while in life will always center about our associations with other individual human beings. I merely ask that we broaden our outlook on mankind and that we apply to the solution of the vast group of complex and important problems presented by the physical and mental characteristics and the social behavior of mankind, the methods that are most potent for giving us a broad and secure knowledge of masses of mankind. In attaining this end we need lose nothing of what we most highly prize in our personal human relations. We shall certainly gain vastly by a realization that with all its apparent chaos, human structure and human function are after all subject to a system of orderly laws.

II

NORMAL AND ABNORMAL HUMAN TYPES

By Clarence M. Jackson

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BY
CLARENCE M. JACKSON

THE division of mankind into racial types has long been a subject of great interest. Ideas have changed greatly from time to time as to the number of races and the basis of classification. Men in various parts of the world differ strikingly in color, which was the first criterion of race to be used. The black, yellow, and white men were traditionally regarded as the descendants of Noah's three sons, Ham, Shem, and Japhet. A fourth human species, the red man (American Indian), was recognized by the great Swedish naturalist, Linnaeus, in his *Systema Naturae* (1735). Later a fifth color variety, the brown man, was added by Blumenbach. This completed the racial classification that is still widely used in the school books.

But it was found that color alone makes an unsatisfactory criterion of race, and other physical traits came to be used as a basis of classification. The shape of the skull or head (relative length or breadth) was recognized as significant by Blumenbach. To measure this trait, Retzius invented the cephalic index, which expresses the skull breadth as a percentage of the skull length. The hair form (straight, wavy, or woolly) and the stature were also used. Various schemes of racial classification were based upon these and other physical characters. Deniker, the French anthropologist, classified mankind under six grand divisions with twenty-nine different races. Nevertheless, increasing information has revealed numerous intermediate forms and transitions between all these races, and none of the proposed classifications has proved satisfactory.

EUROPEAN RACIAL TYPES

The situation may be illustrated by the composition and distribution of the so-called white or Caucasian racial group in

Europe. This group is of especial interest to us as our chief ancestral source. Recent anthropologists generally agree that the modern nations of Europe include three primitive component races, the Nordic (or Teutonic), Alpine (or Celtic), and the Mediterranean (Figure 24). The Nordic type is tall, blond, and long-headed. The Alpine type is somewhat shorter in stature, stouter in build, darker in color, and broad-headed. The Mediterranean type is still shorter and darker, but (like the Nordic) is relatively long-headed. The actual distribution of the traits associated with these racial types is shown somewhat schematically in Ripley's charts of the European map.

First, according to color or pigmentation (Figure 25), it is clear that there is a distinct change from the northern or Scandinavian section, which is predominantly blond in tendency (less than 20 per cent brunette), with gradual transition through Central Europe, which becomes somewhat irregularly but progressively darker in color, to the Mediterranean district, which is over 90 per cent brunette. These figures, of course, refer only to averages. In every district there is always individual variation ranging through all the intermediate stages from extreme blond to extreme brunette. There are also many mixed individual cases, where there is lack of agreement in the pigmentation of the skin, hair, and eyes.

Similarly with stature (Figure 26), it is clear that the averages show generally a progressive decrease from the tall British and Scandinavians in the north to the short Italians in the south; but there are, nevertheless, in every district, individuals showing a wide range of variation in height. The same applies to the cephalic index (Figure 27). The averages in many northern (Nordic) districts approach 75 or lower, indicating narrow or long heads (dolichocephalic). In Central Europe the index increases to above 80, indicating the broad or short heads (brachycephalic) of the Alpine race. In the southern district, the long-headed tendency reappears in the Mediterranean race. But the transitions are somewhat irregular and there is marked individual variation of head form in every community.

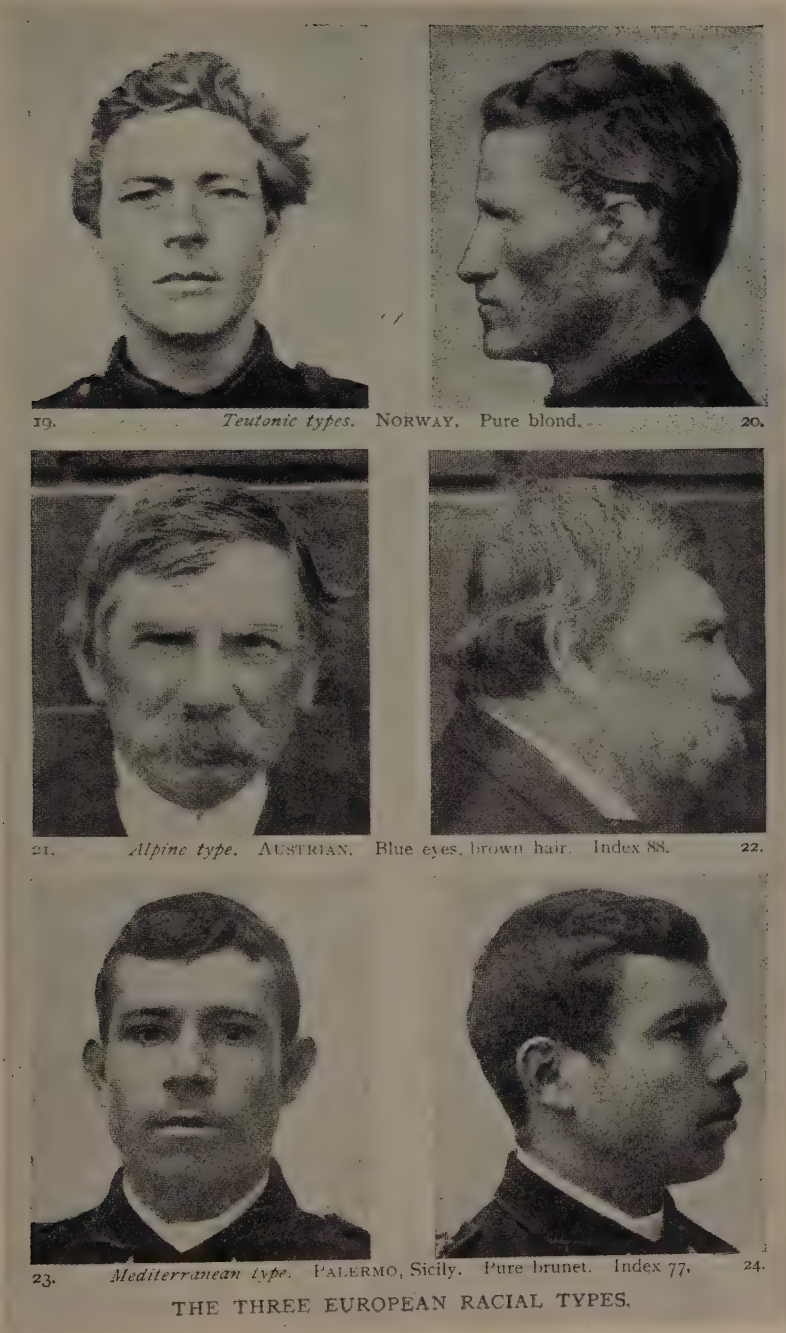
19. *Teutonic types.* NORWAY. Pure blond. 20.
21. *Alpine type.* AUSTRIAN. Blue eyes, brown hair. Index 88. 22.
23. *Mediterranean type.* PALERMO, Sicily. Pure brunet. Index 77. 24.
THE THREE EUROPEAN RACIAL TYPES.

FIG. 24.—The three primary European racial types, Nordic (Teutonic), Alpine (Celtic), and Mediterranean. (Ripley. Races of Europe. D. Appleton & Co., N. Y. 1899.)

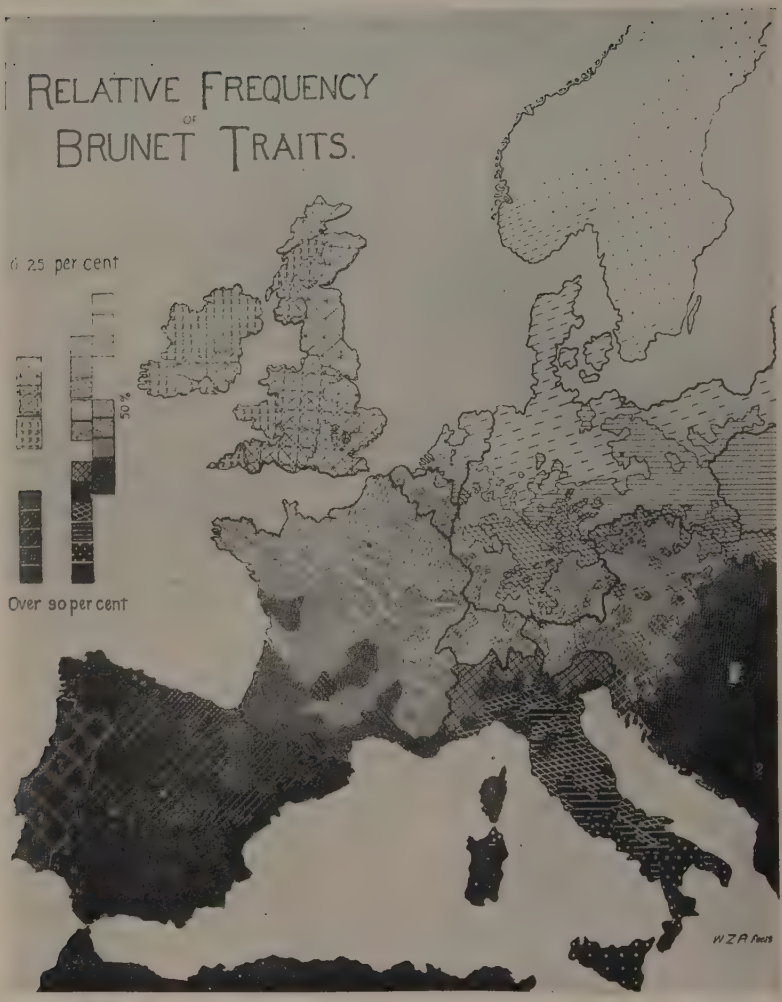

FIG. 25.—The relative frequency of brunette traits, showing the gradual progression from the predominantly blond population of northern Europe to the brunette in southern Europe. (Ripley. Races of Europe. D. Appleton & Co., N. Y. 1899.)

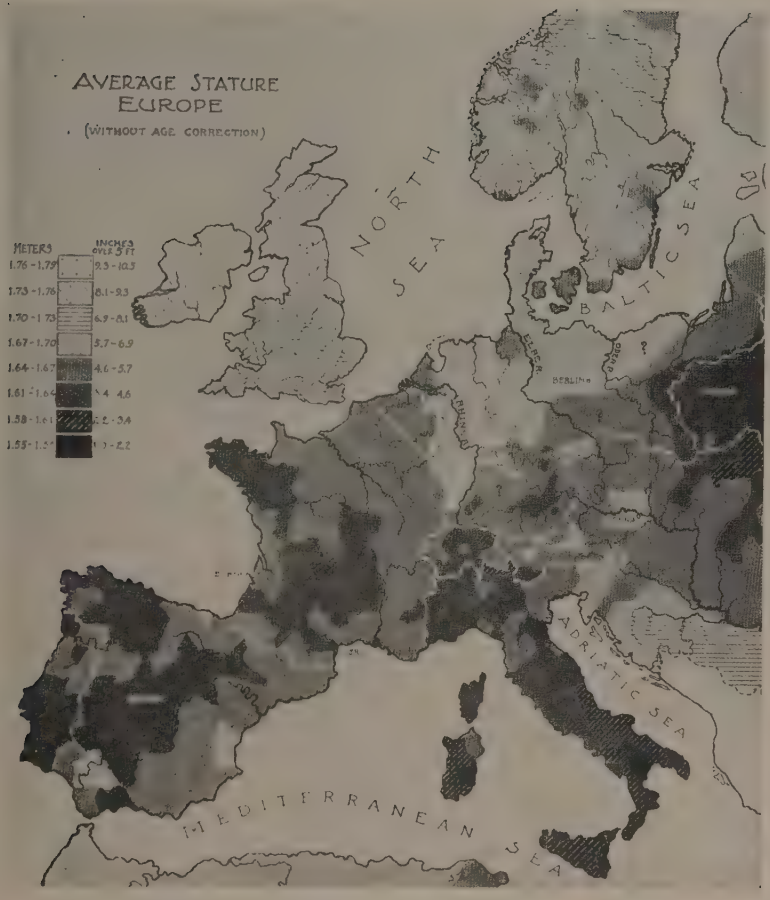

FIG. 26.—Average stature in Europe, showing the somewhat irregular transition from the taller population in the north to the shorter in the south. (Ripley. Races of Europe. D. Appleton & Co., N. Y. 1899.)

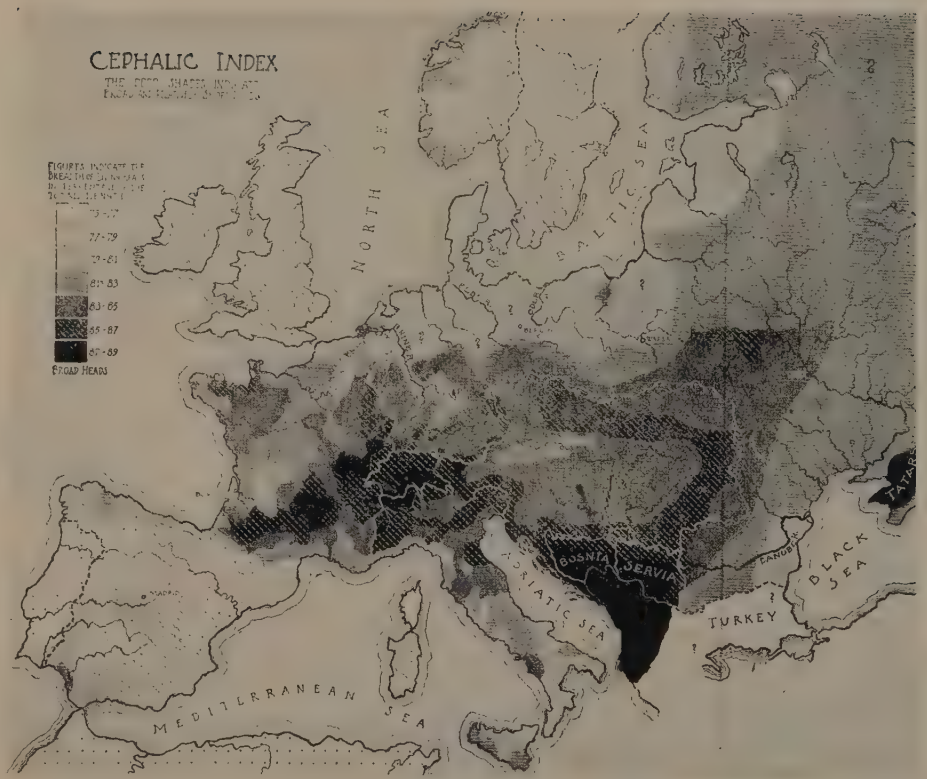

FIG. 27.—Average cephalic index in Europe, showing the regions with broad heads (brachycephaly) in central Europe, tending towards narrow heads (dolichocephaly) in the north and the south. (Ripley. Races of Europe. D. Appleton & Co., N. Y. 1899.)

It is interesting to note that the racial types tend to spread out in three irregular bands or zones, extending from east to west, without regard to national boundaries. Practically all the modern European nations are mixtures from the racial standpoint. France, for example, appears predominantly Alpine (Celtic); but the population of Normandy in Northern France is chiefly Nordic in type, while that of Southeastern France closely resembles the Mediterranean type of Southern Italy. But even in the same racial zone, the conditions are much more complicated than the maps would indicate.

Thus in the case of each component racial trait, be it color, stature, or head form, we find geographical overlapping of types, perhaps due partly to racial intermixture with neighbors. There is also marked individual variability, which occurs in every region. Pure racial types are scarce, but tendencies are usually apparent on careful measurement. In spite of racial intermixture and variation, however, the predominant average or typical physique has apparently endured in many regions of Europe in characteristic form over relatively long periods of time.

Even under new environments, European emigrants may retain persistent racial characteristics of physique, as is shown by the United States draft records during the recent world war (Figure 28). Thus the span (measured by outstretched arms) appears greatest among the descendants of German immigrants. The Scotch (predominantly Nordic) average about three inches taller than those of Italian descent. In weight, the Germans average ten pounds heavier than the Italians or Hebrews.

It is also an interesting fact that most (though not all) of the racial stocks appear to increase in average stature and weight after immigration to America. This may be due to a selected emigrant group with superior physique, or it may be the result of better environmental conditions in America. Possibly both factors may be involved to a variable extent.

AVERAGE DIMENSIONS, EIGHT RACES, DEMOBILIZATION—1919
MEAS. IN CMS.; WT. IN LBS.

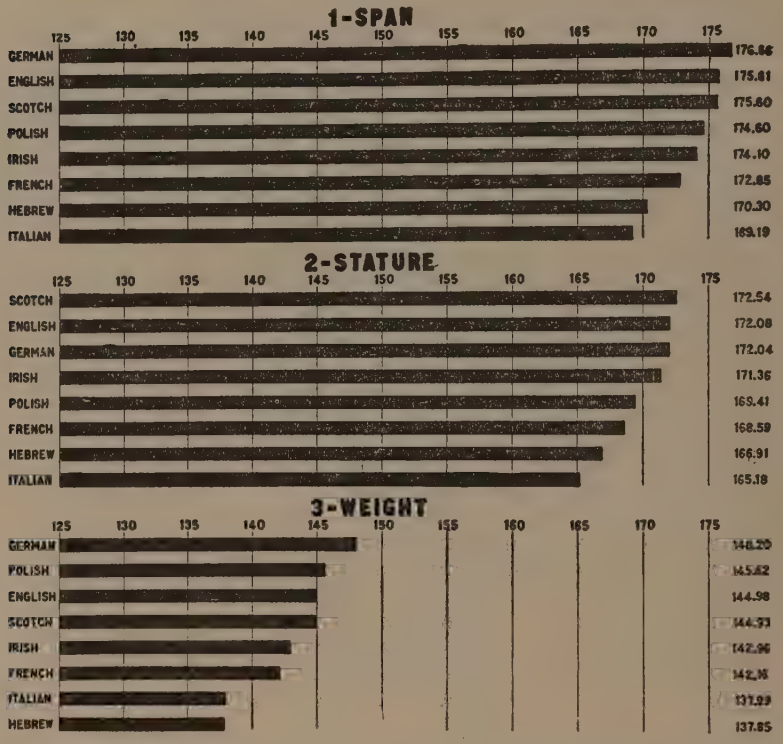

FIG. 28.—Average span, stature, and weight in eight racial groups of the U. S. Army at demobilization in 1919. (Davenport and Love. Army Anthropology. The Medical Department of the U. S. Army in the World War, Vol. XV, Statistics, Part 1, Government Printing Office, Washington, 1921.)

REGIONAL VARIATIONS IN THE UNITED STATES

Some regional characteristics and variations in physique in this country are also shown by the draft records, classified by states and districts. In Figure 29 are shown some maps indicating the averages for various states. In stature, the tallest average is 68.4 inches in Texas, probably with largely Nordic ancestry; the shortest average is 66.4 inches in Rhode Island, popu-

lated from predominantly South European sources. Minnesota, in spite of its largely Scandinavian ancestry, ranks only sixteenth among the fifty states and territories, with an average stature of slightly over 68 inches. In weight, the range among state averages is from 150.5 pounds in Alaska down to 136.4 pounds in Rhode Island. The average for Minnesota is

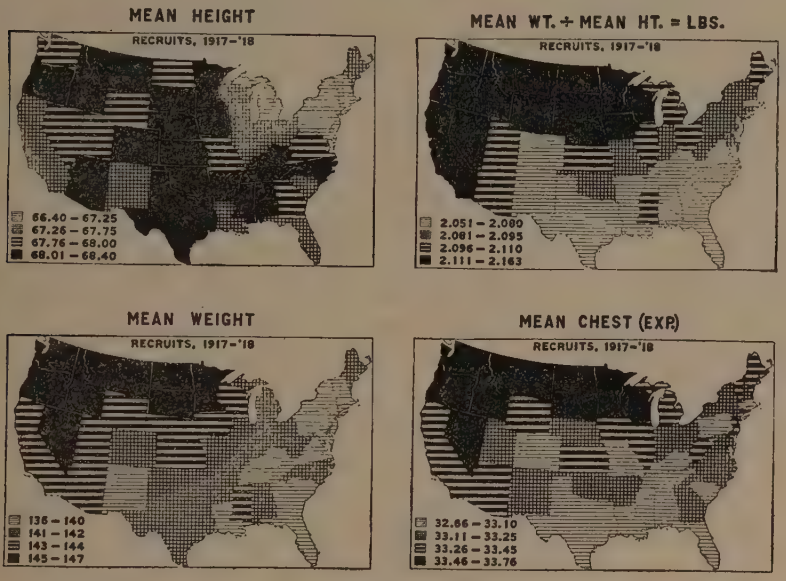

Fig. 29.—Mean height, weight, chest girth, and weight-height index in the various states, according to the U. S. draft records. (Davenport and Love. Army Anthropology. The Medical Department of the U. S. Army in the World War, Vol. XV, Statistics, Part 1, Government Printing Office, Washington, 1921.)

146.4 pounds, ranking fourth, slightly below North and South Dakota. In chest girth, Minnesota also ranks high, being the fifth. It is clear that in general the northwestern group of states represents a region of relatively superior physique, as measured by stature, weight, and chest girth.

We may next compare some averages in physical measurements for the whole country with those for the State of Minne-

sota, and for the four component state districts. And finally, we may compare the corresponding measurements for the University of Minnesota students, as shown by calculations from the University Health Service records for the class of about 1,600 men entering during the year 1924-25. The averages are given in Table 17.

The average stature for the whole United States (first million draft recruits) is about 67.5 inches. The average for Minnesota is about one-half inch taller (68.04). There are, however, significant differences in the four state districts, the averages ranging from 68.44 inches in the northern section down to 67.65 in the Duluth-Range district. The average stature for the latter district is lowered by a considerable number of Finns in the population. In the Twin Cities (Minneapolis and St. Paul) the average is 67.83 inches. The average for the University of Minnesota students is 68.68 inches. This is nearly an inch above the average for the Twin City district (from which a large proportion of the students come), and about two-thirds of an inch above the average for the entire state. It is thus clearly evident that the University students represent a selected group of superior stature.

In weight (Table 17), the average for the United States is 141.5 pounds. For Minnesota, the average is 146.4 pounds, ranging from 148.3 in the northern section of the state to 144.2 in the Twin City district. In contrast with their stature, the weight of the University students is relatively low, the average being only about 141.4 pounds, or nearly the same as the average for the United States. This relatively low weight of the students is accounted for chiefly by their youth, the average age being only about twenty years. As will be shown later, those students who have reached the age of twenty-five (average draft age) have a body weight about equal to the state average.

In chest girth (at expiration), the average for the United States is 33.2 inches, which is the same as that for the Twin Cities, although the Minnesota average is slightly higher (33.6).

TABLE 17

COMPARISON OF UNIVERSITY OF MINNESOTA STUDENTS AND U. S. DRAFT RECRUITS

(Davenport and Love. Army Anthropology. 1921. Jackson. American Journal of Anatomy, Vol. XL. 1927)

STATURE	MEAN IN.	STANDARD DEVIATION IN.
First million draft recruits (21-30 years)	67.49	2.71
Recruits from Minnesota (total 27,341)	68.04	...
Recruits from Northern Minnesota	68.44	2.54
Recruits from Southern Minnesota	68.14	2.63
Recruits from Northeast Minnesota (Range, Duluth)	67.65	2.66
Recruits from Twin Cities (Minneapolis, St. Paul)	67.83	2.63
University of Minnesota students (20.1 years)	68.68	2.52

BODY WEIGHT	MEAN LBS.	STANDARD DEVIATION LBS.
First million draft recruits (21-30 years)	141.54	17.42
Recruits from Minnesota (total 27,341)	146.41	....
Recruits from Northern Minnesota	148.28	16.61
Recruits from Southern Minnesota	147.64	17.31
Recruits from Northeast Minnesota (Range, Duluth)	146.44	16.84
Recruits from Twin Cities (Minneapolis, St. Paul)	144.20	17.48
University of Minnesota students (20.1 years)	141.44	17.35

CHEST CIRCUMFERENCE (Expiration)	MEAN IN.	STANDARD DEVIATION IN.
First million draft recruits (21-30 years)	33.22	2.01
Recruits from Minnesota (total 27,341)	33.63	...
Recruits from Northern Minnesota	33.86	1.86
Recruits from Southern Minnesota	33.86	1.93
Recruits from Northeast Minnesota (Range, Duluth)	33.95	1.98
Recruits from Twin Cities (Minneapolis, St. Paul)	33.18	2.01
University of Minnesota students (20.1 years—*quiet* respiration)	34.86	2.09

TABLE 17—*Continued*

COMPARISON OF UNIVERSITY OF MINNESOTA STUDENTS AND U. S. DRAFT RECRUITS

WEIGHT: HEIGHT^2 INDEX OF BUILD	MEAN
First million draft recruits (21-30 years)	31.08
Recruits from Minnesota (total 27,341)	31.63
Recruits from Northern Minnesota	31.65
Recruits from Southern Minnesota	31.79
Recruits from Northeast Minnesota (Range, Duluth)	31.99
Recruits from Twin Cities (Minneapolis, St. Paul)	31.94
University of Minnesota students (20.1 years)	29.96

CORRELATION BETWEEN STATURE AND WEIGHT	COEFFICIENT OF CORRELATION (r)
First million draft recruits (21-30 years)	.4810±.0006
81,558 U.S. troops at demobilization	.5198±.0017
1,633 University of Minnesota students (20.1 years)	.500 ±.012

The markedly higher average for the students (34.86) is partly because the measurement for this group was taken at quiet respiration instead of expiration (chest fully deflated), the method used in the draft records.

The body build or habitus indicates in general the relative thickness of the body in proportion to its length. It is measured most conveniently by an index of body build, expressed as a ratio between weight and height. For this purpose, the square or the cube of the height is generally preferred, the square being used in the present series. This, according to the English (inch-pound) system, gives an average index of body build of 31.08 for the whole United States (Table 17). The average for Minnesota (31.63) is slightly higher; while that for the University student group (29.96) is decidedly lower. This low

index of body build, or slender physique of the students, necessarily follows because of their superior stature and low body weight, as above mentioned.

Some correlations between stature and weight are also shown in the same Table 17. In general, weight increases with stature, but not regularly or invariably in individual cases. If the weight always corresponded exactly to the height, their coefficient of correlation (r) would be 1.0, as explained by Professor Harris in the introductory lecture of this series. As actually calculated, the coefficient of correlation for the first million draft recruits averaged only 0.48. For a smaller group (about 80,000) measured at demobilization, the average was 0.52. For the University of Minnesota student group the correlation was very similar, the coefficient being 0.50.

Measurements of University of Minnesota Students

To illustrate more fully how human measurements are made and compared, some figures in detail will be shown for various physical characters of the University male student group. These show various "statistical constants" for one whole class of about 1,600, together with the corresponding figures separately for 267 included students of purely Scandinavian descent, and for about 100 of purely German descent. Incidentally, the relatively small number of pure racial (national) descent among the students shows how efficiently the "melting pot" is working in Minnesota.

As to age, the frequency distribution curve (Figure 30) shows first the total number at each year of age (from 16 to 39 years). The mode, or largest group, is at the nineteenth year, although the mean or average is slightly over twenty years. The coefficient of variation is 13.7 per cent. The *relative* distribution curves for the two racial groups separately are very similar in form, but the average for the Scandinavians (20.6 years) is about three-quarters of a year above that for the Germans (19.8 years). Since this age difference is over three times the

probable error of the difference, it is considered significant, i.e., not merely an accident due to chance variation. This means that in comparing the Scandinavian and German groups, in all characteristics that vary with age, this difference must be taken into account in order to avoid errors of interpretation. In our series, the age correction was most easily made

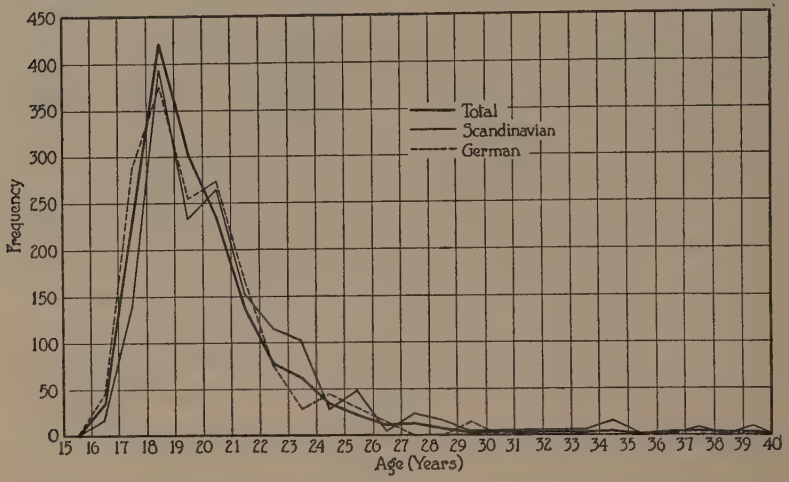

FIG. 30.—Frequency distribution according to age among 1,633 male students entering the University of Minnesota in 1924-25. The relative frequency of those students with purely Scandinavian or German descent is also indicated. (Jackson. American Journal of Anatomy, Vol. XI. 1927.)

by omitting the 17 oldest Scandinavians, leaving a group of 250 almost exactly equivalent in age to the students of German descent.

In stature (Figure 31), the student group ranged from 55 inches (4 ft. 7 in.) up to 78 inches (6 ft. 6 in.), the mean being about 68.7 inches. The double peak in the frequency distribution curve appears statistically insignificant and is probably due to merely accidental variation in distribution. The coefficient of variation in stature is 3.66 per cent, which is about the same as usually occurs in any fairly homogeneous series of adults. The two racial groups are slightly irregular but show the same gen-

eral type of distribution. Both average slightly above the general student body. It is also interesting to note that the German group averages about a quarter of an inch taller than the Scandinavian; but the difference is only about equal to the probable error of the difference and therefore not significant. So the two racial groups are practically equal in average stature.

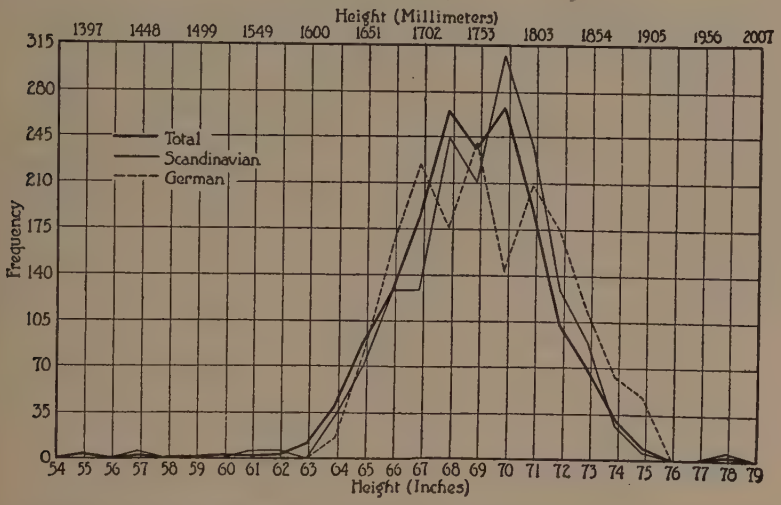

Fig. 31.—Frequency distribution of the stature of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. Height is indicated in inches below the figure, and in millimeters above. (Jackson, 1927.)

In body weight (Figure 32), the range was from 90 to 230 pounds, the average being 141.44 pounds (without clothing). The coefficient of variation is 12.27 per cent, which conforms to what is generally found among adults, the weight being three or four times more variable than the height. The Scandinavian group averages but slightly heavier than the total group. The German average (145.9), however, is nearly four pounds heavier, which is about three times the probable error of the difference and therefore significantly above the general average weight.

In order to visualize more clearly the proportions of the body that are represented by the foregoing measurements, some photographs of individual Harvard students are shown (Figure 33). They happen to correspond in body build very closely to the range found in our Minnesota group. Davenport classifies

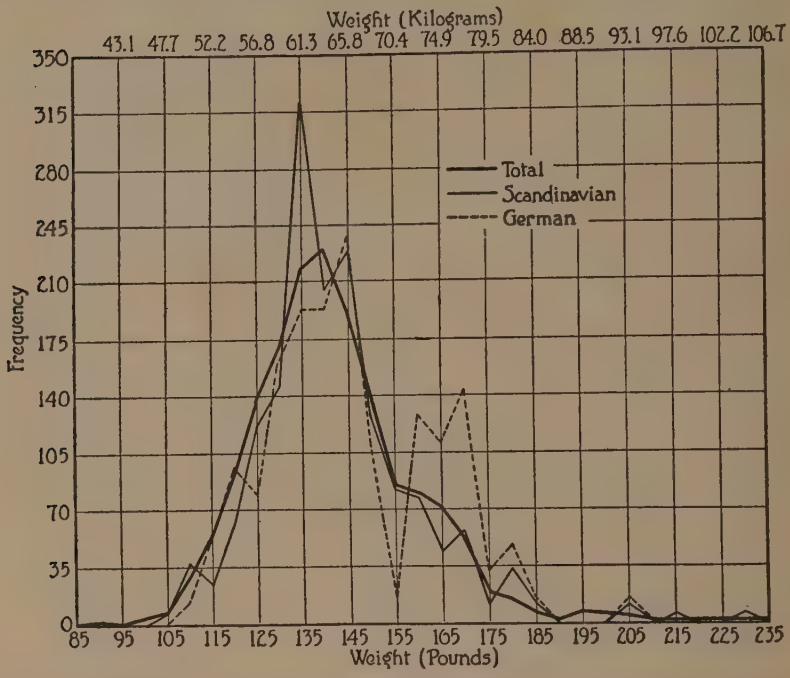

Fig. 32.—Frequency distribution of body weight of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. Weights are given in pounds below the figure and in kilograms above. (Jackson, 1927.)

the individuals shown in the figure as extremely slender, very slender, slender, medium, fleshy, and very fleshy. The weight: height^2 index of body build in this Harvard series ranges from about 22 to 49. The "slender" representative, with body build index of 28, is the one nearest to the Minnesota student average (slightly below 30). According to the usually accepted

standards of normal physique, the average University of Minnesota student ought to have somewhat more meat on his bones.

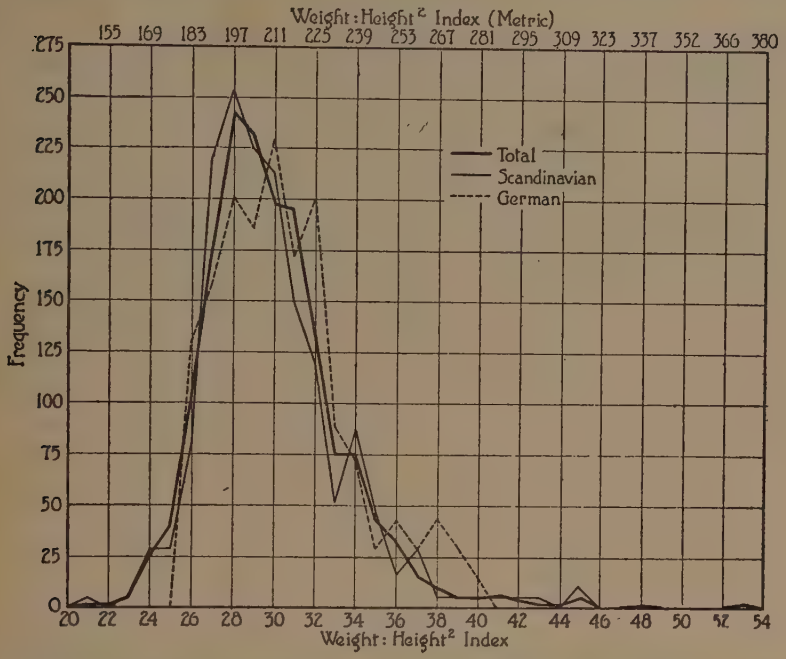

FIG. 34.—Frequency distribution for the index of body build (weight: height² index) of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. The index is indicated according to the English (pound-inch) system below the figure and the metric (gram-centimeter) system above. (Jackson, 1927.)

The next figure (Figure 34) shows the actual frequency distribution curve for the weight: height² index of build in the University of Minnesota group. The range is from 21 to 53, with a mean of 29.96, or practically 30. The coefficient of variation is 10.66 per cent, or slightly less than that for body weight. The Scandinavian index averages slightly lower (29.9); the German significantly higher (30.55). This stouter body build of the Germans corresponds to their heavier weight with practically equal stature. It should be noted that the frequency dis-

tribution curves give no indication of any distinct types of build. Here, as in most of the measurements, we find rather a gradual decrease in frequency as we pass from the mode, or

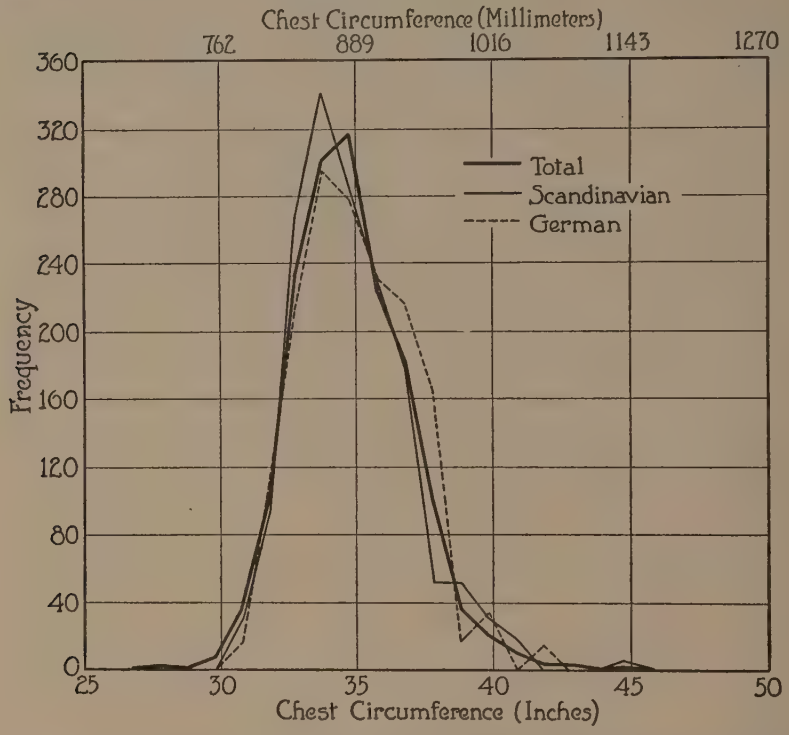

FIG. 35.—Frequency distribution of the chest girth or circumference of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. The measurements are indicated in inches below the figure and in millimeters above. (Jackson, 1927).

group of greatest frequency, toward either of the two extremes. That is, there are all gradations in body build from the medium to the very slender on the one hand and to the very fleshy on the other.

The chest girth (Figure 35) also shows a very regular and symmetrical curve of distribution, with a mean of 34.86 inches (which is almost exactly half the stature). The coefficient of

variation is 5.99 per cent, which is much greater than that for stature. There is no significant difference in chest girth between the two racial groups of students.

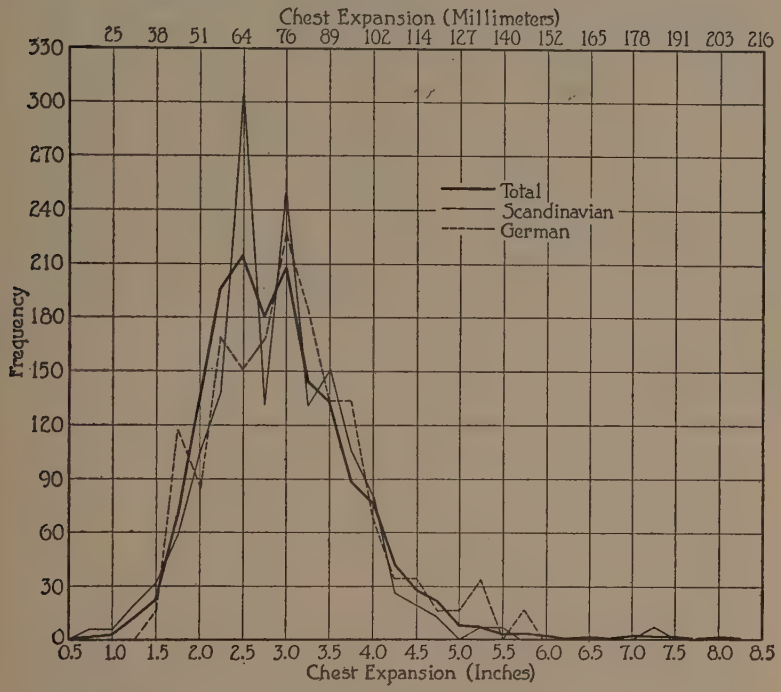

FIG. 36.—Frequency distribution of the chest expansion of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. The measurements are indicated in inches below the figure and in millimeters above. (Jackson, 1927.)

The chest expansion, or difference in girth between inspiration and expiration, as measured by the tapeline, appears much more irregular (Figure 36). The range is from 1 to 8 inches, with an average of 2.9 inches. The coefficient of variation is 28.75 per cent, which indicates that the chest expansion is nearly five times more variable than the chest girth. The average chest expansion is slightly higher for the German group, but the difference is of doubtful significance.

The vital capacity is the volume of air that can be expelled from the lungs after a full inspiration. The measurement is made with a spirometer. It is a rough measure of the lung capacity. The range of individual variation in the student group (Figure 37) is from 1,400 to 6,500 cubic centimeters, with a

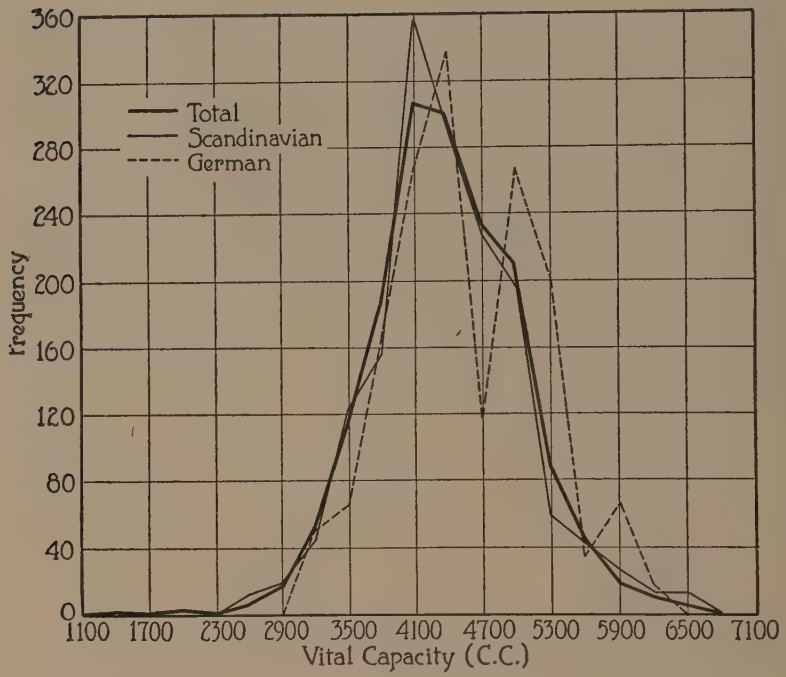

FIG. 37.—Frequency distribution of the vital capacity of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. Measurements are taken by the spirometer in cubic centimeters. (Jackson, 1927.)

mean of 4,383 cubic centimeters, or nearly five quarts. The coefficient of variation is 14.54 per cent, which is only half that for the chest expansion, but more than double that for the chest girth. The vital capacity of the German group is significantly higher than that for the Scandinavian or the total group of students.

The pulse rate varies from 23 to 127, with a mean of about 80 per minute (Figure 38). The distribution curve shows three distinct peaks or modes at 71, 79, and 95, which appear to be statistically significant. Their meaning is uncertain and requires further investigation. The coefficient of variation for the pulse rate is 15.1 per cent, or about the same as that for the

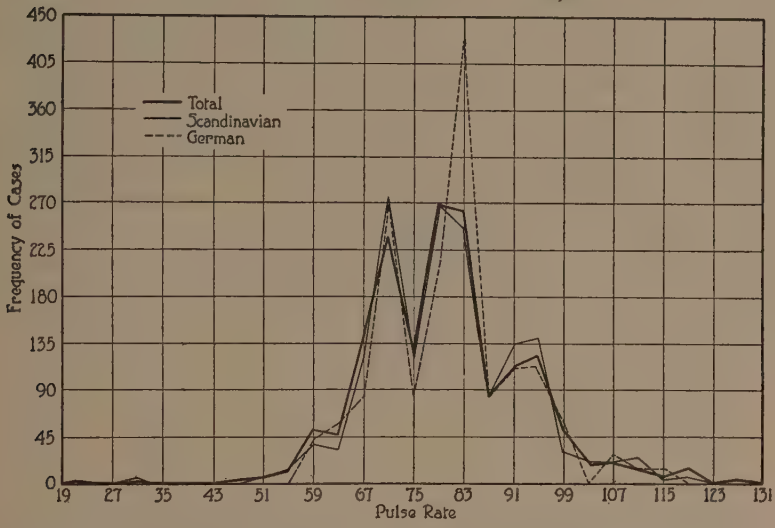

FIG. 38.—Frequency distribution of the pulse rate per minute of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. (Jackson, 1927.)

vital capacity. There is no significant difference between the racial groups. It is apparent that physiological functions like the pulse rate can be measured and compared in the same way as morphological or anatomical characters.

The systolic blood pressure ranges from 80 to 175, with a mean pressure of about 124 millimeters of mercury (Figure 39). The distinct peaks of the distribution curve in this case are easily explainable on the basis of the psychology of the observers. They usually tend to make the readings in even tens rather than at intermediate points on the scale. The coefficient of

variation in blood pressure is 9.9 per cent, which is distinctly lower than that for pulse rate and vital capacity. No significant racial difference in blood pressure was found.

Correlations between Measurements

We have hitherto considered the measurements for various individual anatomical and physiological characters, including for each the range, frequency distribution, mean or average,

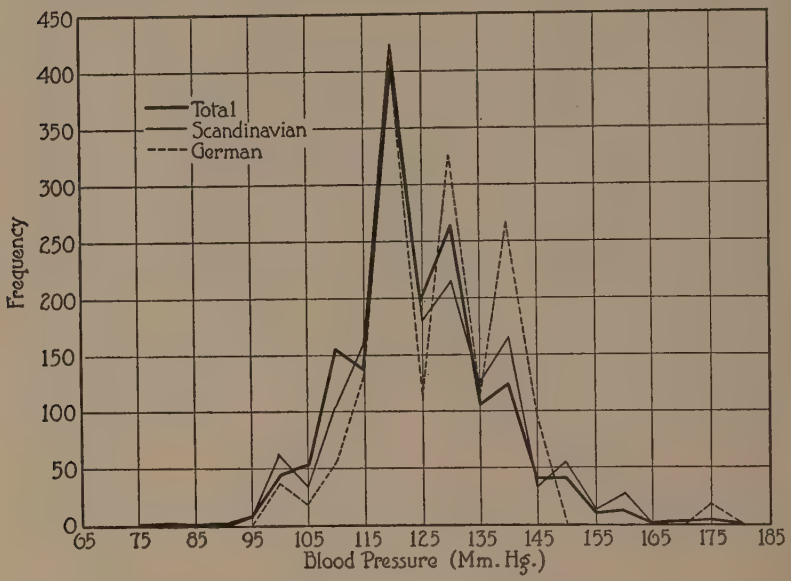

Fig. 39.—Frequency distribution of the systolic blood pressure of the male students at the University of Minnesota. Relative frequency also is indicated for those of Scandinavian or of German descent. Measurements are given in millimeters of mercury. (Jackson, 1927.)

and variability. It is frequently important also to know how various characters are associated with each other in their variations. As was explained in the introductory lecture by Professor Harris, this associated variation for any pair of characters is measured by their coefficient of correlation (r). As previously mentioned, for perfect correlation the coefficient is 1.0, while for entire independence of variation the coefficient is 0.

The next chart (Figure 40) shows what are technically called the regression lines for stature and age. It represents the average age stature distribution in our group of 1,600 students when they are sorted out according to their years of age. You will observe that there are some slight irregularities, but no regular or consistent increase in height from the younger to the older groups. (Dotted lines indicate less than ten cases to the year, and may therefore be ignored on account of the small num-

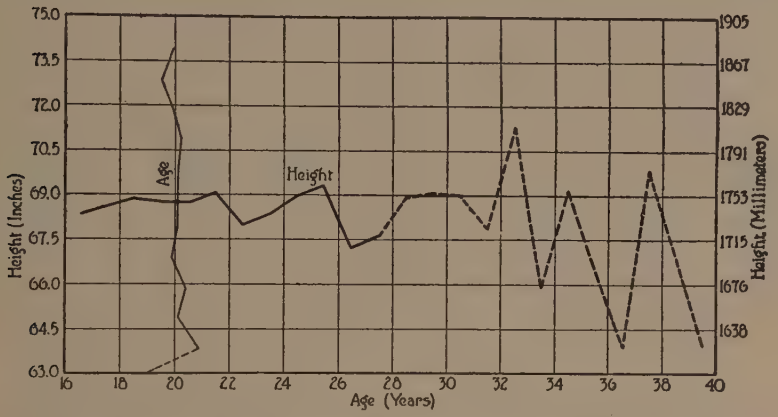

FIG. 40.—Regression lines indicating the correlation between height and age of the male students at the University of Minnesota. The light line indicates the average age at corresponding heights, and the heavy line the average height at corresponding ages. Dotted line indicates less than ten cases in the corresponding groups, which therefore are more irregular and less reliable. The height is indicated in inches on the left of the figure and in millimeters on the right. (Jackson, 1927.)

bers.) The coefficient of correlation (r) in this case is $-.034 \pm .017$, which is of very doubtful significance since it is only twice the probable error. This early attainment of the maximum stature in the student group is very remarkable, because in the general population an increase of three or four inches may be expected in young men after the age of sixteen. Possibly the explanation may be that the students entering the University at the earlier ages are, on the average, of superior physique, corresponding to their precocious mentality. This would

tend to raise the average stature for the younger members of the entering class.

In the case of weight and age (Figure 41) the relations are quite different. Here we see an unmistakable increase in body weight with age after sixteen years. The weight increase is at

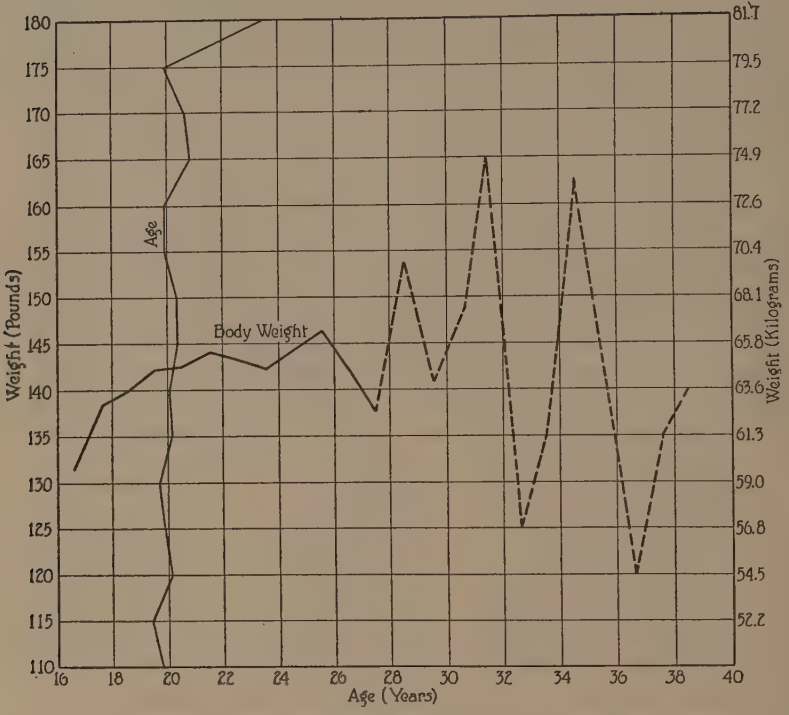

FIG. 41.—Regression lines indicating the correlation between body weight and age of the male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

first more rapid than slower, reaching an average of about 145 pounds at the age of twenty-five years. Later, as indicated by the dotted lines, the number of cases is too small to make dependable averages. The coefficient of correlation (r) is $.095 \pm .025$, which indicates a low but significant correlation between body weight and age. Since the regression line in this

case is distinctly curved, rather than straight in tendency, the correlation is more accurately indicated by a different method, giving a higher "correlation ratio" of .171 ± .016.

When the average body weight is compared with height or stature (Figure 42), the regression line for weight shows a

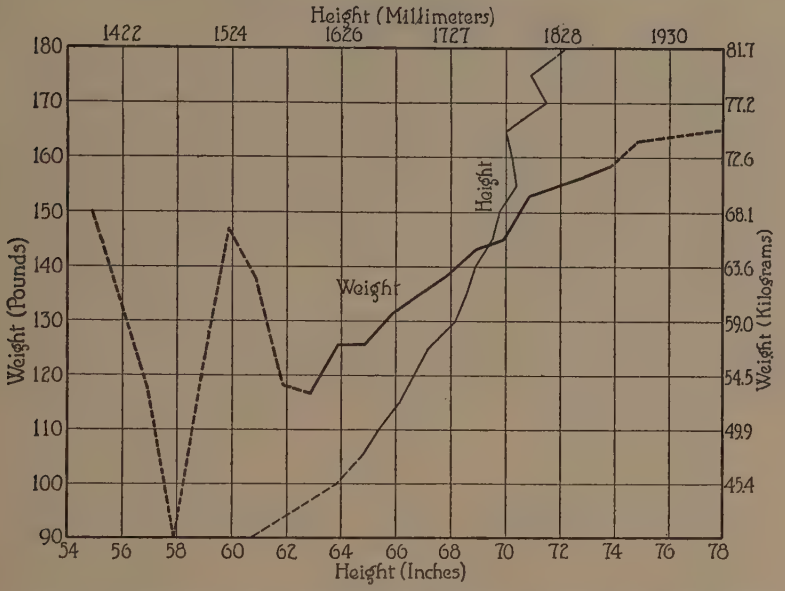

FIG. 42.—Regression lines indicating the correlation between weight and height of the male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

steady increase of about three pounds per inch. The coefficient of correlation (r) in this case is .500 ± .012, which is about what is usually found among adults, and indicates relatively good (though by no means perfect) correlation.

The regression lines for the index of body build and age (Figure 43) are more irregular, especially at the extreme ends, but on the whole a definite increase in body build with age is evident. This signifies a progressively stockier build, which necessarily follows from the increasing body weight with sta-

tionary stature. The coefficient of correlation (r) between body build and age is $.298 \pm .015$, which indicates only a moderate degree of association. The following charts will show the correlation of body build with several other anatomical and physiological characters.

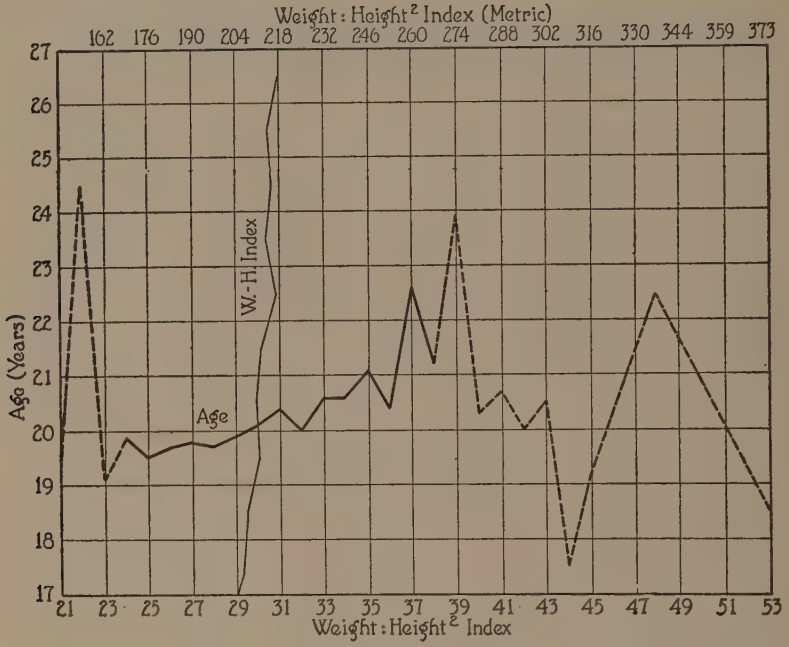

Fig. 43.—Regression lines indicating the correlation between body build (weight: height² index) and age of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

The increase in chest girth or circumference with body build (Figure 44) is very regular (aside from the dotted extreme ends of the regression line), giving a coefficient of correlation (r) of $.672 \pm .009$. This is the highest degree of correlation found in the present series, and indicates that, as might be expected, the body build is rather closely associated with the size of the chest girth.

The chest expansion (Figure 45), on the contrary, shows a

nearly horizontal regression line, with no significant change according to body build. The coefficient of correlation (r) is $.021 \pm .017$, indicating practically no association. One might expect a heavy-set person to have a greater chest expansion than a slender person, but this usually is not the case. It may

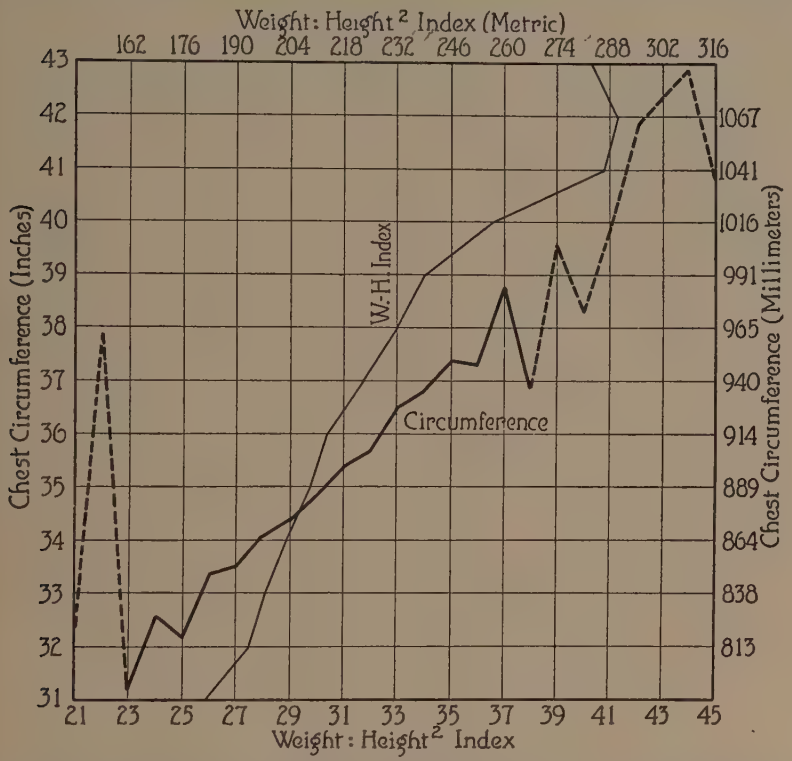

FIG. 44.—Regression lines indicating the correlation between body build (weight: height² index) and chest circumference of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

be added that the vital (lung) capacity has only a very moderate degree of correlation (0.35) with the chest expansion. This indicates that the importance of chest expansion has probably been somewhat overrated in medical examinations for life insurance, military service, and similar purposes.

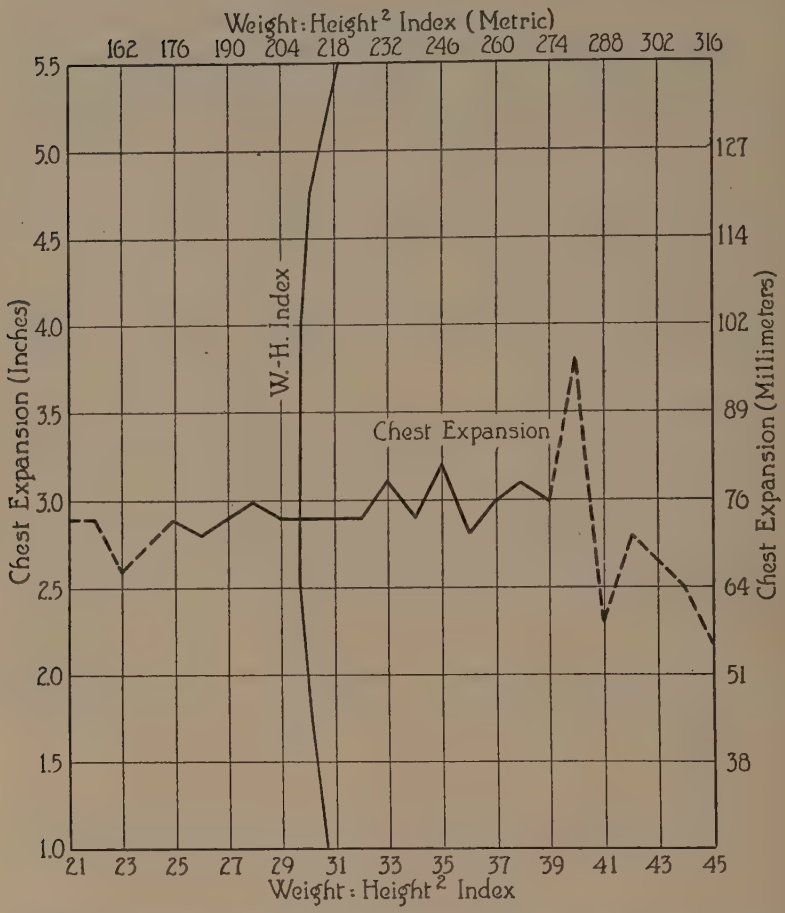

FIG. 45.—Regression lines indicating the correlation between body build (weight: height² index) and chest expansion of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

The next chart (Figure 46) shows that vital capacity increases with body build; i.e., stouter persons, although not having a greater chest expansion, do tend to have a greater lung capacity, at least up to a certain point. As indicated by the upper end of the curve, the obesity of extremely stout persons probably interferes with their lung capacity. The coefficient of

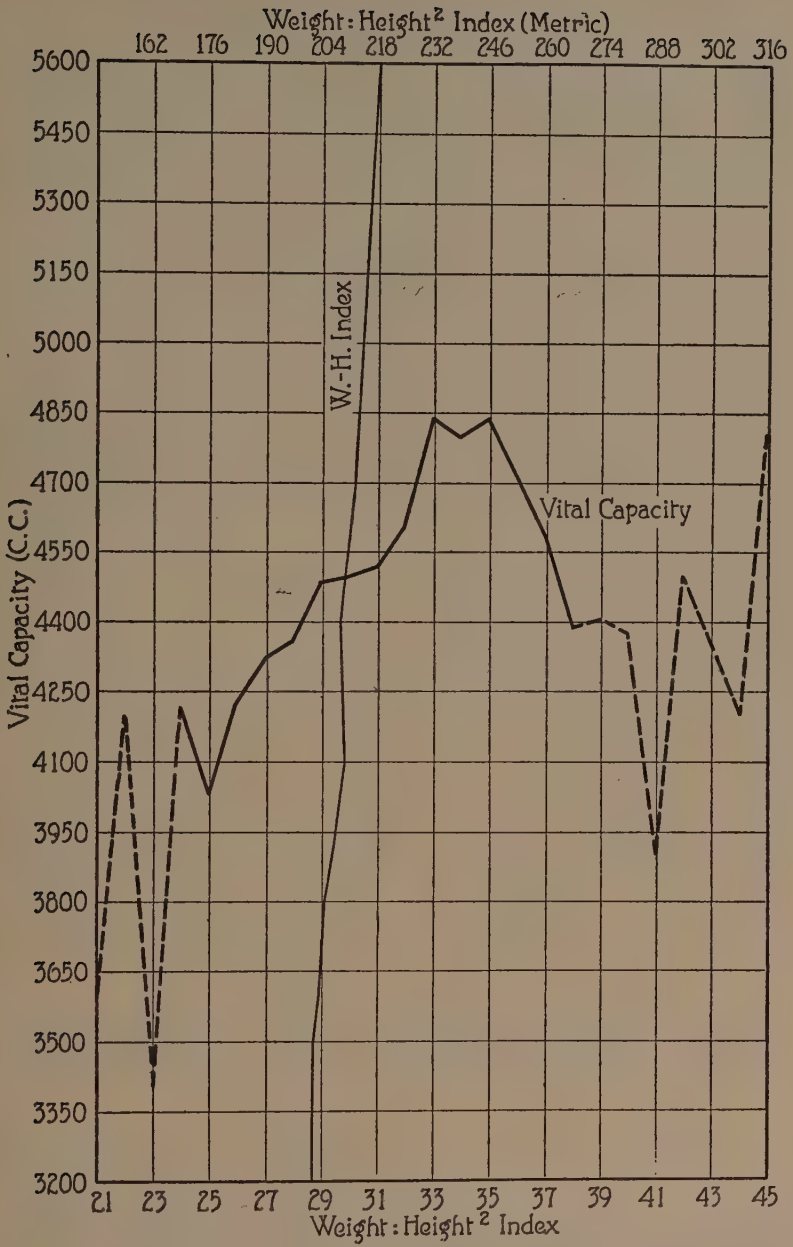

FIG. 46.—Regression lines indicating the correlation between body build (weight: height² index) and vital capacity of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

correlation (r) is only .188 ± .016, which is low, indicating that the two characters are not very closely related. Since the regression line is not straight in this case, the correlation is better indicated by the "correlation ratio," which is .302 ± .015.

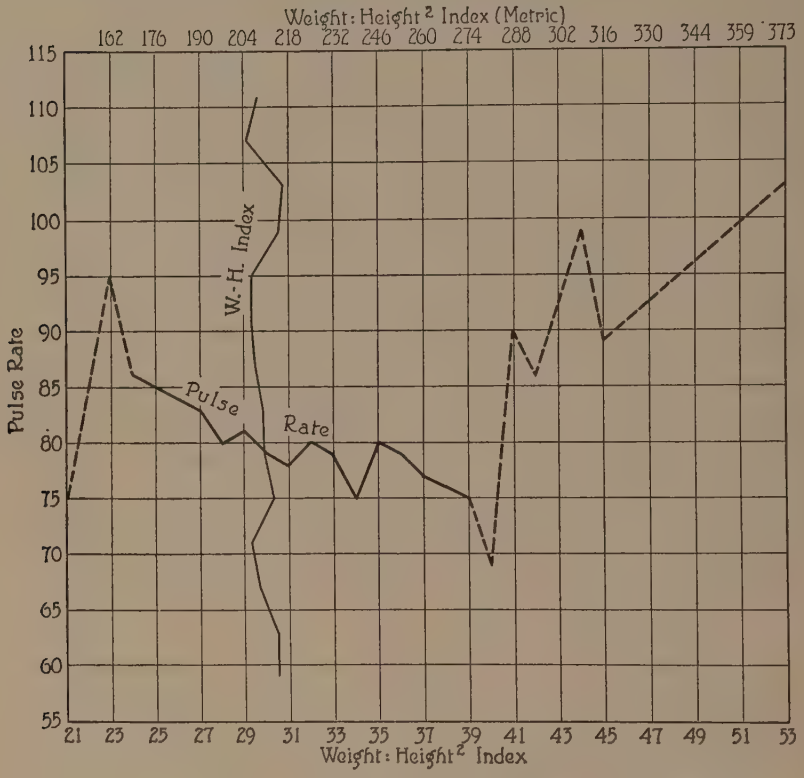

FIG. 47.—Regression lines indicating the correlation between body build (weight: height² index) and pulse rate of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

In the case of the pulse rate (Figure 47), the line of regression (excepting the extreme portions) clearly slopes downward from left to right. This gives a *negative* correlation coefficient (*r*) of —.095 ± .017, indicating that stouter individuals tend to have a somewhat slower pulse rate.

The regression line for systolic blood pressure (Figure 48) shows a slight but irregular tendency to rise, with a low correlation coefficient (r) of $.062 \pm .017$. This shows that the well-

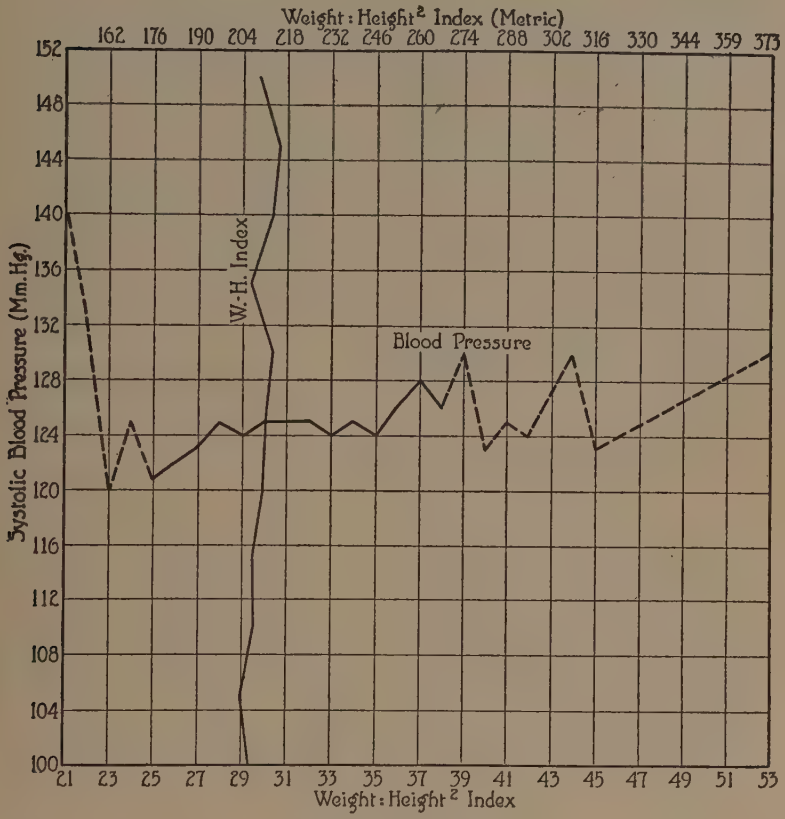

Fig. 48.—Regression lines indicating the correlation between body build (weight: height² index) and systolic blood pressure of male students at the University of Minnesota. See explanation under Fig. 40. (Jackson, 1927.)

recognized tendency of fleshy individuals to have a higher blood pressure is not very evident in this group of University students.

In the comparison of various average measurements (weight, stature, chest girth, and vital capacity) of students at Minne-

sota and at other universities (Wisconsin, Cornell, Amherst, and Yale), it appears that the averages are all higher at Minnesota (Table 18). In some cases, however, the differences are small and perhaps insignificant. In a few instances data have

TABLE 18

AVERAGE MEASUREMENTS FOR MALE STUDENTS IN VARIOUS AMERICAN COLLEGES AND UNIVERSITIES

(From Jackson. American Journal of Anatomy, Vol. XL. 1927)

UNIVERSITIES	AGE IN YEARS	STATURE MM.	SITTING HEIGHT MM.	CHEST GIRTH MM.	BODY WEIGHT KG.	VITAL CAPACITY CC.
Minnesota	20.1	1745	889	885	64.2	4383
Amherst *	20.8	1725	903	880	61.2	3780
Cornell *	...	1725	904	884	61.2	4240
Yale *	20.3	1724	903	875	63.0	4000
Harvard †	18	1727	...	...	64.9	....
Harvard ‡	18-25	1744	...	...	65.9	....
Penn. State ** .	19.2	1707	...	...	62.5	4006
Stanford †† ...	18-30	1759	915	...	68.5	4421-4646
Wisconsin * ..	20.1	1726	903	878	63.3	4050
Wisconsin ‡‡ ..	20.8	1728	898	(exp.) 833	63.4	....

* Data from Seaver ('05). Numbers not stated.

† Data from Lee ('15) for 662 Harvard freshmen.

‡ Data from Castle ('16) for 1,000 Harvard students (gymnasium records).

** Data from Forsythe and Lewis ('16) for 581 freshmen in Pennsylvania State College.

†† Data from Hewlett and Jackson ('22) and Rogers ('23) for two selected groups of 400 each.

‡‡ Data from Bardeen for 1,238 men entering the University of Wisconsin in 1922 (average age is for the preceding year).

been published (from Stanford University, for example) indicating a significantly higher stature, body weight, and vital capacity. These were for selected groups of students, however, and not for the whole class, which would probably give somewhat lower averages.

Types of Body Build

In the preceding discussion of the body build, it was shown that the medium build passes gradually into the two extremes, with no indication of distinct classes or types. However, the stout "hypersthenic" and the slender "asthenic" forms, under various synonyms and with various intermediate grades, have been recognized by many anthropologists and medical students of constitutional anatomy (Figure 49). The significance of these extreme builds is therefore a matter of much interest. In the first place, it should be noted that the difference between these two extreme conditions is not merely in the amount of body fat present. The preceding discussion has shown that the body build is more or less closely correlated with various features of the respiratory and circulatory apparatus. Many other differences between these types in their structure and internal organization have also been observed. Whether they represent true biological types (biotypes) is still uncertain.

The question as to the nature and causes of these differences in body build has been much discussed and disputed. Some have thought that the differences are purely environmental and caused by variations in nutrition and other hygienic factors. These factors are admittedly important, but they cannot explain the fact that under the same environment some races, families, and individuals remain slender, while others have a strong tendency to become stocky or corpulent.

In addition to the environmental influences, there are undoubtedly inborn or hereditary factors which are usually the most important in determining the body build. From the developmental or genetic standpoint, there are various theories to account for the hereditary differences in the build of the offspring.

One possible explanation is the "pure line" theory of Johannsen (Figure 51). He found that when ordinary (Princess) beans are sorted out according to size (length) they show the

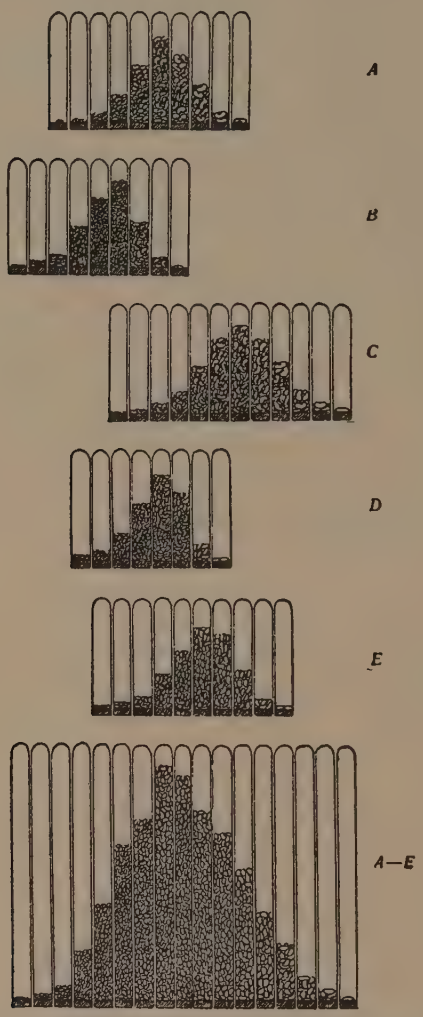

FIG. 51.—Diagrams representing the frequency distribution of beans according to size in five pure-line series, A, B, C, D, and E. The mixture of all these in the ordinary bean harvest gives the symmetrical frequency distribution represented in the lower part of the figure. (Johannsen, in Brugsch-Lewy's Biologie der Person, Lfg. 1, 1926, p. 237.)

usual type of frequency distribution. The medium-sized beans are most numerous, with rapidly decreasing numbers of the progressively smaller-sized (to the left of the figure), or of the larger-sized (to the right). Now if size is hereditary, we might expect that the large beans would always tend to reproduce the larger size, the small beans the smaller size, and the medium-sized beans intermediate. But this is not the case. Johannsen demonstrated that when these beans are separated and propagated by self-fertilization, the collective lot can be shown to consist of five distinct "pure lines," each of which reproduces beans varying only within certain narrow limits, as appears in the figure. Group B, for example, represents a relatively "dwarf" strain, averaging much smaller than group C, a larger strain. There is, however, some overlapping between the larger variates of the B strain and the smaller variates of the C strain. The other groups are intermediate in their modes or averages, and all combined will give the apparently simple or unimodal type of frequency distribution shown in the lower part of the figure.

Whether the human population likewise consists of something comparable to "pure line" strains is yet uncertain. Human beings cannot reproduce by self-fertilization, and the process of cross breeding greatly complicates the question. Davenport has made a careful and extensive study of the inheritance of body build in man. He concludes that there are in the germ cells of each sex a number of different factors determining body build. The number varies from zero to two (or possibly three) factors for fleshy build in each individual germ cell. Thus if two "fleshy" factors in the male germ cell are joined with two similar factors in the fertilization of the female ovum, the result would be a very fleshy offspring. Similarly if "fleshy" factors were absent from both germ cells, the result would be very slender offspring. Combinations giving one, two, or three "fleshy" determiners would yield intermediate types of body build (modified, of course, to some extent by varying condi-

tions of the environment, also by age and sex). If there are three different hereditary factors for body build instead of two, the number of possible combinations would be correspondingly increased. While it is possible that the heredity of body build may thus be explained by the theory of multiple factors, it must be admitted that the statistical evidence is as yet scarcely sufficient to establish this theory with certainty.

But whatever may be the mechanism that ultimately determines the human body build, this mechanism undoubtedly works to a large extent through a set of small organs known as the endocrine or ductless glands. One of the most important of these is a gland in the neck, the thyroid gland, whose enlargement produces goiter. If this gland is rudimentary or deficient in secretion during infancy the body and mind are stunted and dwarfed, extreme cases resulting in a peculiar condition of idiocy known as cretinism. Figure 52 shows such a cretin girl, who at the age of 14 years was still clearly in the infantile stage of development. One of the most brilliant medical discoveries was the possibility of supplying the deficient secretion, thus transforming such an idiotic dwarf into a relatively normal child, as shown in the lower figures. Older cretins become very stocky, obese dwarfs, who may be somewhat improved but cannot be cured by thyroid medication. Thus hypothyroidism, with deficient thyroid secretion, tends to produce a stout body build; while hyperthyroidism (through excessive function of the thyroid), on the contrary, tends to cause a slender type of body.

Another organ that also has a great influence in determining the body build is the pituitary gland or hypophysis. This is a very small gland, deeply located at the base of the brain. When this gland fails to function properly during the period of development, one of the commonest effects is the so-called "dystrophia adiposogenitalis." Body fat accumulates in abnormal amounts and the genital organs remain relatively undeveloped. Figure 53 shows an extreme case of this type in a boy of sixteen

years. All the intermediate stages may occur between such extreme cases of hypopituitarism and normal individuals.

In the opposite condition of hyperpituitarism, where the pituitary gland (hypophysis) is enlarged, with excessive secretion, the result is quite different. If this condition arises during the growth period, typical gigantism results. Most of the giants have enlarged pituitary glands, as has been found at autopsy in many cases, and can be shown even during life by an examination of the skull with the X-rays. If the excessive function of the pituitary gland does not occur until after growth is completed, gigantism may not result; but there is a very characteristic and striking change in the form of the body, and especially of the face, as shown in Figure 50. The photographs reveal in this man an almost incredible change in the features between the normal at twenty-five years of age and the condition (termed "acromegaly") at thirty-eight. The change in this case developed gradually over a period of eight years. The features become markedly coarser, lips thickened, lower jaw overgrown and protuberant, and extremities (hands and feet) greatly enlarged. The expanded bony pocket containing the enlarged pituitary gland can be seen in such cases as a light area in the X-ray picture of the base of the skull.

Several other ductless glands in the body are also concerned to a somewhat lesser extent in the development and control of the body build, but they must be passed over for lack of time. In a recent book, Berman has given a popular, but somewhat exaggerated, account of the ductless glands as determiners of human physique and personality.

In conclusion, brief reference must be made to another significance of the body build in medicine. Since even ancient times, physicians have recognized such types as the slender "habitus phthisicus" and the stout "habitus apoplecticus." In recent years, much interest has been revived in the general subject of "constitutional medicine," which seeks to learn what types of body build are especially predisposed or resistant to the

various forms of disease. While much still remains to be worked out in this field, certain general facts stand out clearly, as shown especially by many thousands of life insurance records.

TABLE 19

RELATIONSHIP OF BODILY HABITUS TO DISEASE ACCORDING TO THE LIFE INSURANCE RECORDS

(Assicurazione Generali. Florschutz, Trieste. 1926)

CAUSE OF DEATH	PHYSIQUE		
	Thin Per Cent	Medium Per Cent	Stout Per Cent
Tuberculosis	25.7	13.1	4.1
Apoplexy	4.9	9.2	12.3
Circulatory disturbances	9.4	14.8	22.7
Pneumonia	11.7	10.3	7.7
Malignant tumors	6.4	8.3	7.1
Infectious disorders	5.4	4.6	4.1
Brain disorders	10.6	9.8	6.6
Suicide	4.7	5.1	4.1
Various other diseases	21.1	24.8	30.5
Total	100	100	100

As an example, some recent findings from Italian (Austrian) life insurance records are shown (Table 19), which in most respects are in essential agreement with similar records from America, Germany, and other countries. The causes of death are tabulated for each type of physique (thin, medium, or stout). Of all cases classified as "thin" at the time when the insurance examination was made, over 25 per cent died later of tuberculosis, while only 4 per cent of the "stout" class died of this disease. That is, the chances for death from tuberculosis were six times greater for the thin than for the stout. The "habitus phthisicus" therefore appears to be a reality, and not imaginary. It is further evident that the "stout" class were especially predisposed to apoplexy and circulatory troubles,

while the "thin" appear much more predisposed to pneumonia and brain disorders. Although some troubles, such as malignant tumors (cancer), infections, and suicide, show no special difference either way, it is clear that in many important diseases the type of body build is very significant. This difference in physique may also be important in explaining certain racial characteristics in susceptibility and predisposition to disease. In the future, therefore, more precise measurements of the body and more exact determinations of the various types of body build are likely to become of increasing importance in medicine as well as in anthropology.

III

PERSONALITY AND PHYSIQUE

By Donald G. Paterson

PERSONALITY AND PHYSIQUE

BY

DONALD G. PATERSON

I. INTRODUCTION[1]

MODERN techniques in the measurement of mental development make possible a new attack upon the age-old problem of the relation between bodily and mental traits. This problem received attention long before anyone dreamed of measuring objectively either the growth of intellect or the relation between this growth and specific physical characteristics. Indeed, Aristotle is credited with having produced the first systematic treatise on physiognomy wherein are described the physical signs and symptoms of mental traits. Physiognomy, palmistry, and phrenology survive to this day as pseudo-scientific, non-scientific, and even anti-scientific formulations of the assumed dependence of personality upon physical development and physical type.

The scientific approach to the problem busied itself with concrete, quantitative studies of one or another physical character, always seeking to relate each physical measurement to some criterion of mentality. At first attention centered on the more obvious structural characteristics of the body such as height, weight, and especially head diameters and proportions. Measurements of these features were then brought in line with such available evidences of mental ability as teachers' estimates and scholastic standing. Of course in recent years these studies have more frequently utilized standardized intelligence tests.

Toward the end of the first decade of the present century, a fascinating field of research emerged, in which subtle aspects of physical status were probed in an effort to find crucial in-

[1] The writer is indebted to Dr. R. M. Elliott for many helpful suggestions and criticisms in preparing the manuscript of this lecture for publication.

dices of the physical traits that would be more intimately related to mental traits than those hitherto mentioned. The phenomena associated with the onset of puberty were seized upon as highly significant of physiological status, and it was hoped that these would afford a physical basis for mental classification. The discovery of the Roentgen rays opened up the possibility of measuring the progress of ossification of the skeletal bones, and straightway many experiments were undertaken to prove that these indices are of great importance in connection with normal mental development. Standards for interpreting the significance of the time of teeth eruption were also drawn up with the claim that dentition would be found to be associated with mental growth. Finally, efforts were made to develop a suitable index of body build in the belief that relative physical proportions would prove to be definitely related to mental efficiency and temperament.

Throughout the history of all these efforts to find a physical basis for mental traits, the hypothesis was maintained that mind is dependent upon or conditioned by physical growth and status. That is, if physical development be accelerated, then mental development would be facilitated, whereas if physical growth be delayed or impaired in any way, there would be a corresponding retardation or impairment in mental growth. Furthermore, there is a suggestion that these varied approaches were made under the influence of a conviction that some sort of unitary factor dominates all phases of growth; and hence the search always aimed to discover that single physical trait which would best reveal this guiding principle.

The foregoing statement sketches in broad outlines the problem before us. It remains to fill in details with sufficient refinement to indicate the present status of scientific knowledge on the subject. In a rough way, we propose to follow the chronological sequence of discovery, since, in fact, scientific knowledge emerges from the cumulative efforts of many workers, many of whom perforce must grope somewhat blindly.

II. NON-SCIENTIFIC AND PSEUDO-SCIENTIFIC ATTACKS ON THE PROBLEM

1. Popular Beliefs

Belief in the mental significance of particular physical features has long dominated the thoughts of mankind. The prevalence of such phrases as "long-headed" or "high brow" in popular speech testifies to the survival of physiognomic beliefs among persons many of whom may even be unaware that systematized treatises on physical characterology exist. It is worth noting that the phrase "long-headed" connotes primarily something psychological, such as shrewdness or farsightedness. It is difficult to recognize the metaphor and realize that the term literally describes the dolichocephalic head shape. Likewise, "high brow" now connotes superior intellect and learning, with scarcely any immediate physical reference to actual height of forehead.

Our playwrights and novelists are greatly aided in their attempts at character delineation by the existence of similar widespread beliefs. The villain must be a brunette, with shifty eye, and smooth, oily manner. The fickle coquette, of course, is most generally blond, small of stature, with the bloom of youth upon her cheek. The stooping miser inevitably possesses long, bony fingers. Herr Professor, in shiny frock coat, is round-shouldered, near-sighted, and somewhat anaemic in appearance. The successful business man strides forth, alert and energetic, smooth shaven, hair graying at the temples. The vampire is the extreme brunette, with lustrous eyes half-concealed under purple lids. Of course, the jolly and carefree bachelor, who wins his way by means of wit and fun, simply must be somewhat rotund so that when he laughs he laughs all over. Then there is the sharp-tongued neighborhood gossip or busybody, thin to the point of emaciation, with long beak-like nose, and altogether plain and unprepossessing, if not downright ugly. There is no end to these human stereotypes from Chaucer to

Hollywood. Perhaps Shakespeare more than anyone else has set the stage: prodigious Falstaff; distrusted Cassius with "lean and hungry look"; Hamlet cloaked in black, slow in movement, saturnine in countenance; and a hundred others.

Analogical reasoning has contributed much to the establishment of belief in the essential unity of physical and mental qualities. By analogy, men possessing physical traits similar to certain animals are endowed with the behavior characteristics known to be possessed by those animals. The person with the bulldog jaw is assumed to be tenacious, persevering, and relentless in carrying out plans and purposes; or witness the hangdog look of the wrongdoer suddenly exposed; the sheepish look, the foxy face, the cow-like expression—each example brings emphasis to the point.

2. Physiognomy, Animal and Human

A long section of Lavater's four-volume work on physiognomy (second edition, published in 1804) is devoted to demonstrating that there is a science of animal physiognomy as well as human physiognomy.[2] A few quotations selected here and there from the second volume will illustrate the extent to which analogical reasoning has run riot in this field. "If any one would endeavor to discover the signs of bravery in man, he would act wisely to collect all the signs of bravery in animated nature, by which courageous animals are distinguished from others." "It cannot be doubted but that the human head, here annexed, has something of the ox; though it appears to me rather to partake of the ox and lion, than the ox singly." "The skull of the ox expresses patience, resistance, difficulty of being moved, a great desire of feeding." "Whoever contemplates the middle line of the mouth of the living hyena, will there discover the character, the very index, of the most inexorable malignity." "As the characters of animals are distinct,

[2] John Caspar Lavater. Essays on physiognomy: for the promotion of the knowledge and the love of mankind. Trans. by Thomas Holcroft. 2d Ed. 4 Vols. C. Whittingham, London. 1804.

so are their forms, bones, and outlines. From the smallest winged insect to the eagle that soars and gazes at the sun, from the weakest worm, impotently crawling beneath our feet to the elephant or the majestic lion, the gradations of physiognomical expression cannot be mistaken. . . . . Were the lion and lamb, for the first time, placed before us, had we never known such animals, never heard their names, still we could not resist the impression of the courage and strength of the one, or of the weakness and sufferance of the other." "Each species of beast has, certainly, a peculiar character, as it has a peculiar form. May we not hence, by analogy, infer that predominant qualities of the mind are as certainly expressed by predominant forms of the body, as that the peculiar qualities of a species are expressed in the general form of that species?"

The argument from analogy is not restricted to the animal realm as may be seen from the following quotations from the same source. "May not souls also have a determinate capacity, proportionate to the form and organization of the body? (Water which takes the form of the vessel.)" "Large oranges have thick skins, and little juice. Heads of much bone and flesh have little brain. Large bones, with abundance of flesh and fat, are impediments to mind."

The reader of Lavater is immediately impressed with the almost infinite number of relations held to exist between variations in all sorts of physical features and qualities of mind. Lavater, perhaps chief of the physiognomists from Aristotle to the present time, recognized this complexity and subsumed them under "One Hundred Physiognomical Rules."[3] They cover characteristics of the forehead, eyes, eyebrows, nose, cheeks, mouth, chin, and various facial proportions. Warts and moles have special significance. Rule LXXVII states that "A broad brown wart on the chin is never found in truly wise, calmly noble persons"; Rule LXXXVII, that "A long, projecting, needle-formed, or a strong, curled, harsh, rough hair,

[3] Lavater. *Op. cit.* Vol. IV.

springing from a brown mole or spot on the chin or neck denotes, in a most decisive manner, very great voluptuousness, which is rarely unaccompanied by great imprudence and indiscretion"; Rule LXXIII, that "Women with brown, hairy, bristly warts on the chin, especially the under part of the chin, or the neck, are commonly industrious, active, good housewives, but extremely sanguine, and amorous to folly, or even to frenzy. They talk much, and would willingly talk only of one object. They are easily excited to kindness, but not as easily prevailed on to become indifferent. They must be treated with circumspect, calm friendship, and kept at a distance by a mildly cold dignity of demeanor."

To men of science the absurdity of such physiognomic assertions is no less evident than is their quaint ingeniousness to the sophisticated and realistic layman of today. Certainly no obligation rests upon any of us to consider seriously their possible validity, based as they are upon opinion derived from unsystematic and casual observation with no shred of supporting quantitative evidence.

Modern physiognomic "doctors" (a flourishing profession even in the twentieth century) go far beyond Lavater to include characteristics such as blondness, voice quality, texture of skin, bodily build, posture, hardness or softness of muscles, gait, handshake, gestures, clothing, etc. Katherine Blackford, perhaps, holds first rank among modern exponents of physiognomy. Her system of character analysis is based upon nine fundamental physical variables: (1) color, (2) form, (3) size, (4) structure, (5) texture, (6) consistency, (7) proportion, (8) expression, and (9) condition.[4]

We may gain a good idea of her system by selecting her exposition of the so-called law of color as illustrative. In describing blond versus brunette characteristics, she states: "In brief, always and everywhere, the normal blond has positive, dynamic,

[4] Katherine M. H. Blackford, M. D. and Arthur Newcomb. The job, the man, the boss. Doubleday, Page & Co., New York. 1919.

driving, aggressive, domineering, impatient, active, quick, hopeful, speculative, changeable, and variety-loving characteristics; while the normal brunette has negative, static, conservative, imitative, submissive, cautious, painstaking, patient, plodding, slow, deliberate, serious, thoughtful, specializing characteristics." [5] Furthermore, Dr. Blackford assures us on the same page that her law of color is simple and straightforward. To quote: "In applying this law of color to people of the white race, the method is simple. The less the pigmentation in any individual, the more marked will be the characteristics of the blond in his physical, mental, and psychical nature; the greater the degree of pigmentation, the more marked the characteristics of the brunette."

It occurred to the writer that such positive assertions might well be put to a quantitative test and, in collaboration with Dr. Katherine E. Ludgate, an attempt at verification was undertaken.[6] We held that if blonds as a group, always and everywhere, possess or exhibit traits that are positive, dynamic, driving, etc., then blonds individually should possess such traits. If such is the case, then at least a majority of blonds should be rated by intelligent, educated judges as being the possessors of those traits. Furthermore, a large majority of blonds should be rated as being deficient in the brunette traits. The opposite results should hold, of course, in securing ratings on brunettes.

Accordingly we prepared a rating sheet on which were listed the twenty-six traits in random order. Each of ninety-four judges was asked to select from among his acquaintances two pronounced blonds and two pronounced brunettes and to rate them with respect to the presence or absence of each trait or characteristic. In this way we secured ratings on 187 blonds and 187 brunettes.

The ratings for blonds and brunettes were tabulated separately and the percentage of blonds rated plus (+) in each

[5] *Ibid.* p. 141.

[6] Donald G. Paterson and Katherine E. Ludgate. Blond and brunette traits: a quantitative study. J. Person. Res., 1:122-127. July, 1922.

trait and the percentage of brunettes rated plus (+) in each trait was then computed. The detailed computations are shown in Table 20 and a graphic representation of the same facts is shown in Figure 54. It is obvious that these so-called blond and brunette traits fail to differentiate real flesh-and-blood blonds and brunettes. The percentage of brunettes possessing the blond traits is approximately as high as the percentage of blonds possessing blond traits. Likewise the percentage of blonds possessing brunette traits is also very similar to the percentage possessing brunette traits. Such a result is at complete variance with the result to be expected if Dr. Blackford's generalization were true.

The same experiment was repeated by Kenagy of the Carnegie Institute of Technology, who secured the cooperation of sales managers in some forty national organizations in rating 152 highly successful salesmen (82 blonds and 70 brunettes).[7] The results are almost identical with our results, thus disposing of Blackford's claims with reference not only to the so-called law of color but incidentally also to her application of the method in the selection of salesmen.

One other attempt to verify experimentally one of Blackford's assertions may be mentioned in passing. Hull reports the work of one of his students (Alice L. Evans) on "convex" versus "concave" profiles.[8] Blackford has stated: "The significance of the pure convex type is energy, both mental and physical. Superabundance of energy makes the extreme convex keen, alert, quick, eager, aggressive, impatient, positive, and penetrating. . . . . The pure concave, as might be expected, is the exact opposite. . . . . The keynote of his character is *mildness*. . . . . He is slow of thought, slow of action, patient in disposition, plodding."[9] By means of an ingenious measuring device, Hull and Evans carefully measured the precise degree of con-

[7] H. G. Kenagy. Do blonds make the best salesmen? Sales Management. February, 1923. p. 325-328.

[8] C. L. Hull. Aptitude testing. World Book Co., Yonkers. 1928. p. 127-130.

[9] Blackford and Newcomb. *Op. cit.* p. 154-156.

TABLE 20

PERCENTAGE OF BLONDS AND BRUNETTES RATED PLUS (+) IN EACH OF BLACKFORD'S SO-CALLED BLOND AND BRUNETTE TRAITS

(After Paterson and Ludgate)

TRAITS	PERCENTAGE RATED PLUS (+)	
	187 Blonds	187 Brunettes
Blond		
Positive	81	84
Dynamic	63	64
Driving	49	50
Aggressive	62	56
Domineering	36	36
Impatient	56	51
Active	88	82
Quick	70	68
Hopeful	85	85
Speculative	53	51
Changeable	53	43
Variety-loving	66	62
Average	64	61
Brunette		
Negative	16	17
Static	28	31
Conservative	51	61
Imitative	39	40
Submissive	25	26
Cautious	54	60
Painstaking	56	61
Patient	43	52
Plodding	27	31
Slow	20	24
Deliberate	47	57
Serious	58	72
Thoughtful	67	70
Specializing	52	45
Average	42	45

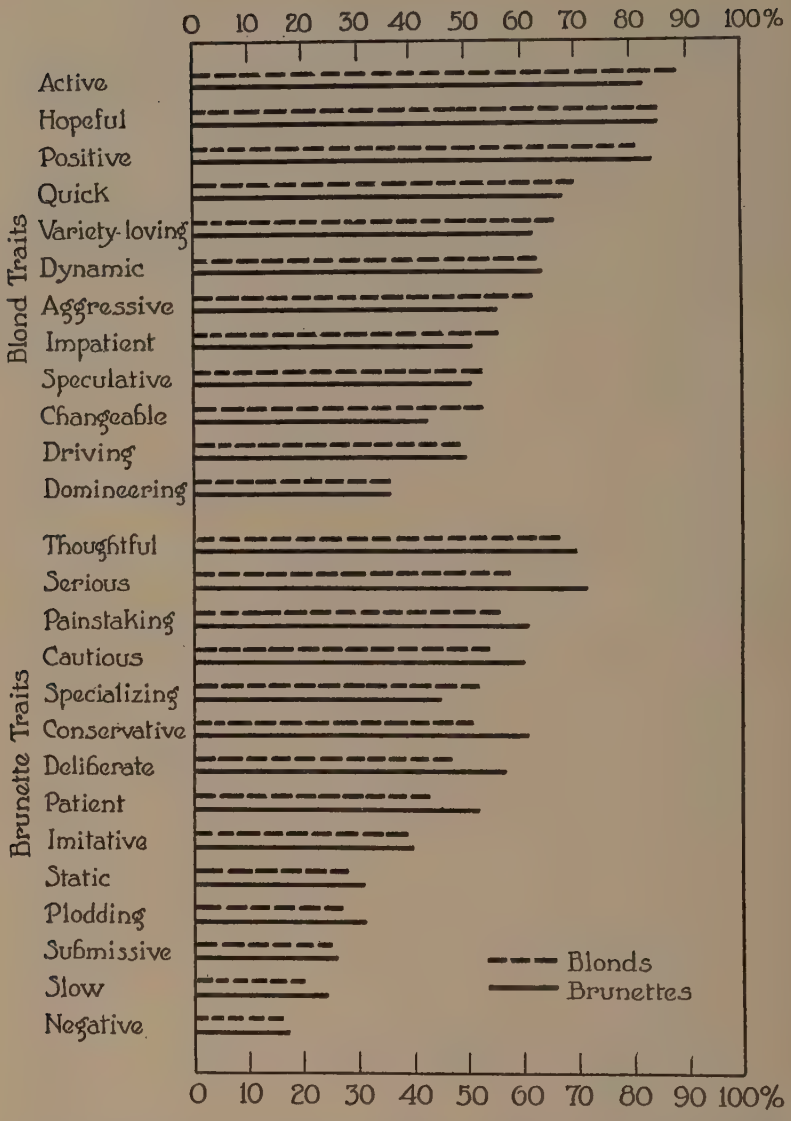

FIG. 54.—Bar diagram showing percentage of blonds and brunettes rated plus (+) in each of Blackford's so-called blond and brunette traits. (Paterson and Ludgate.)

vexity of the profiles of each of twenty-five members of a university sorority. Five different measurements of convexity were obtained. These measurements were then correlated with a series of character-trait ratings secured by having each sorority member rate the others. Character traits rated were optimism, activity, ambition, will power, domination, and popularity. With such a small number of subjects the resulting coefficients of correlation would naturally have very high probable errors and hence would fluctuate within rather wide limits. As a matter of fact the thirty coefficients ranged from —.27 to +.39, sixteen being negative and fourteen positive. The best indication of the real relationship between convexity of profile and these character traits would seem to be an average of the thirty coefficients. This, when computed, turns out to be +.01, a figure that is as close to zero as would be expected if chance alone were operating.

In her book, *Reading Character at Sight,* Blackford gives only one bit of quantitative evidence and this happens to bear upon the convex-concave profile.[10] Asserting that the convex profile indicates quickness in seeing, thinking, deciding, and acting, she holds that, since taxicab drivers must possess just such mental traits, they must also possess convex profiles. It is reported that one of her students began classifying the profiles of taxicab drivers with the result that the great majority were actually found to possess the convex profile. However, later on in her book she set at naught the quantitative proof of her theory by inadvertently stating that the majority of the people in the United States have convex profiles. Thereby, she merely proved that, in respect to profile, taxicab drivers constitute a fair sampling of the American population. It is obvious that satisfactory scientific evidence would have required: (1) actual measurement of the degree of concavity or convexity of the profile of each taxicab driver; (2) actual measurement of the same fea-

[10] Katherine M. H. Blackford. Reading character at sight. Independent Corporation, New York. 1918. p. 18-20.

ture for another group of men of similar age, schooling, race, and economic and social class, but engaged in work that does not involve such mental qualifications; and (3) demonstration of a statistically significant difference between the two groups in the measurements secured. Needless to say, no physiognomist adopts such laborious and tedious methods of proof.

Perhaps the most elaborate attempt to verify physiognomic claims is to be found in the work of Cleeton and Knight.[11] One hundred and twenty-two physical measurements were considered in testing the hypothesis that judgment, intelligence, frankness, will power, ability to make friends, leadership, originality, and impulsiveness are revealed by various physical characteristics. Ratings of these character traits as exhibited by the thirty subjects employed in the experiment were secured from intimate associates and pooled in such a manner as to yield an unusually reliable index of those traits. These pooled ratings were then correlated with each of the physical measurements, with the net result that the average of 201 correlations between variations in physical traits and variations in character traits (presumed by character analysts to be closely related to the physical traits) is exactly zero. Here is a beautiful statistical refutation of the sweeping claims indulged in by devotees of physiognomy.

It is true that carefully controlled experiments have not yet been performed utilizing as working hypotheses all of the seductive assertions put forth by physiognomists. Such studies as have been made, however, yield monotonously negative results. Nevertheless, scientific caution compels us to admit the possibility of extracting a few kernels of truth from these pseudoscientific systems. Even a rigorous thinker like Kelley cautiously states of physiognomy: "None of these methods has established itself as having more than the faintest suggestion of validity. The writer finds it hard to believe that this will always

[11] G. U. Cleeton and F. B. Knight. Validity of character judgments based on external criteria. J. Appl. Psychol., 8: 215-229. 1924.

be so and in truth expects that some day the analysis of mental ability and of emotional characteristics will be clearly furthered by quantitative and qualitative measures, facial contours, and expressions." [12]

Woods, who is best known for his study of mental and moral heredity in the royal families of Europe, seems to have shown a positive correlation between size of nose and ability.[13] He assembled photographs of both eminent and nondescript persons, and although dependent on estimates of nose length, he showed that a significant difference in respect to that characteristic obtains between superior and ordinary mortals, concluding, "The majority of great men have large or long noses, the remainder nearly always have noses of at least average size." It is possible, of course, that an accidental linkage in heredity between this particular physical characteristic and ability in some of the families in his sampling of eminent persons gave rise to the apparent significant correlation. That there is no necessary or inevitable relationship between size of nose and intelligence is shown by Sommerville in his study of the physical and mental characteristics of about one hundred Columbia University students.[14] The correlations between various facial measurements and the Thorndike three-hour intelligence examination for high school seniors and college students hover around zero. The detailed results are shown in Table 21. It is difficult to see how such slight relationships as are demonstrated by Sommerville can be interpreted in any other way than as tending to refute current physiognomic claims. Negative results emerging from actual measurements seem to throw doubt upon Woods's conclusions supported by less accurate methods.

[12] Truman Lee Kelley. Interpretation of educational measurements. World Book Co., Yonkers. 1927. p. 107-108.

[13] F. A. Woods. What is there in physiognomy? I. The size of the nose. J. Hered., 12: 301-318. 1921.

[14] R. C. Sommerville. Physical, motor, and sensory traits. Arch. Psychol., No. 12. p. 1-108. 1924.

The failure of physiognomical assertions to meet the test of actual measurements is beautifully illustrated in an incidental investigation undertaken by Sir Charles Goring, whose monumental labors culminated in a complete overthrow of the Lombrosian school of criminal anthropology.[15] This incidental study was an inquiry regarding the validity of belief in the intellectual significance of a high or a low brow.

TABLE 21

COEFFICIENTS OF CORRELATION BETWEEN VARIOUS FACIAL MEASUREMENTS AND THORNDIKE INTELLIGENCE TEST SCORES OF 105 COLUMBIA UNIVERSITY STUDENTS

(After Sommerville)

THORNDIKE INTELLIGENCE TEST SCORE AND	r	PE_r
Nose length	+.10	.06
Length of lower jaw (horizontal ramus)	+.09	.06
Nose length ÷ length of lower jaw	+.01	.06
Face length	—.05	.06
Face width	+.09	.06
Height of lower face (infradental-menton)	—.05	.06
Distance between eyes (interpupillary space)	—.04	.06
Distance between eyes ÷ face width	—.13	.06
Palpebral index: width of eye opening ÷ length of eye opening	—.12	.06
Gonial angle	—.14	.06

He secured for each of 300 convicts official ratings or estimates of (a) intelligence and (b) height of forehead. Four grades of intellect: "intelligent," "unintelligent," "weak-minded," and "imbecile" were distinguished in the rating scale. Since the raters had had ample opportunity to observe the behavior of these convicts in the process of assigning each to a suitable occupational task, there is good reason to believe that

[15] Sir Charles Goring. The English convict. H. M. Stationery Office, London. 1913. p. 28-29.

the estimates of intelligence submitted by them were fairly accurate.

Analysis of the results seemed to indicate a marked tendency for the more intelligent to have high foreheads and the less intelligent to have low foreheads. Of those judged "intelligent," 20.5 per cent were also judged to have high foreheads, whereas only 8 per cent of those judged as "imbecile" were judged to have high foreheads. Conversely, 46 per cent of the imbecile group as contrasted with 20.5 per cent of the intelligent group were judged to have low foreheads. Results for the other two intermediate intelligence groups were in line with this trend.

Thereupon Goring actually measured the height of the foreheads of these 300 convicts. These actual measurements plotted in relation to the four intellectual grades revealed an astonishing reversal of the supposed trend. The median height of forehead for the intelligent group was 50 mm.; for the unintelligent group 52 mm.; for the weak-minded group 54 mm.; and for the imbecile group 53 mm. Fourteen of the most intelligent group were found to have lower foreheads than any of the imbeciles!

How can we account for the discrepancy in results? Apparently the convict known to be intelligent was judged to have a high forehead and the known weak-minded convict to have a low forehead, in utter disregard of what would be the findings by precise measurement. Apparently the error in the estimation of height of foreheads arose as a result of belief on the part of the raters in the intellectual significance of a high brow or a low brow.

We are indebted to Goring for his convincing demonstration of the non-validity of the "high brow, low brow" superstition. Goring's proof that human judgment may be seriously in error in estimating such a simple, observable physical characteristic as height of forehead throws grave suspicion on all

character-analysis schemes that rely upon casual observation instead of precise physical measurements.

3. Phrenology

Phrenology, originated by Gall and Spurzheim toward the close of the eighteenth century, exhibits the same sort of anecdotal evidence in behalf of the intimate causal nexus in which physical and mental are presumed to be involved. Early discoveries concerning brain localization encouraged the hypothesis that every trait of character and every mental aptitude had its own assigned localization in the brain. The law of exercise was invoked to assist in the determination of these specific brain areas, on the assumption that if a given mental trait were much used, then its corresponding brain part would be enlarged through exercise. As a particular portion of the brain became enlarged, it was supposed to press against the skull, thus causing an enlargement or protuberance at that point. Thus reading character through the bumps on the head becomes a simple matter—simply look over the skull, note bumps, and instantly you know just what parts of the brain are unusually developed and hence what mental characteristics predominate in that person's total make-up. Complicated and minute maps of the surface of the skull were drawn to represent each important mental or moral trait, or faculty, as it was originally called. Present-day phrenological maps differ little from the original maps of Gall and Spurzheim in spite of the progress that has been made in neurology during the past one hundred years. We may take, as illustrative, the phrenological map shown in Fowler's book (p. 28) which had such a great vogue in the United States during the latter half of the nineteenth century.[16] The map is reproduced in the upper part of Figure 55. Such localizations as were postulated we now know to be wrong. For purposes of comparison, the lower part of

[16] O. S. Fowler. Human science: or phrenology. National Publishing Co., Philadelphia. 1873.

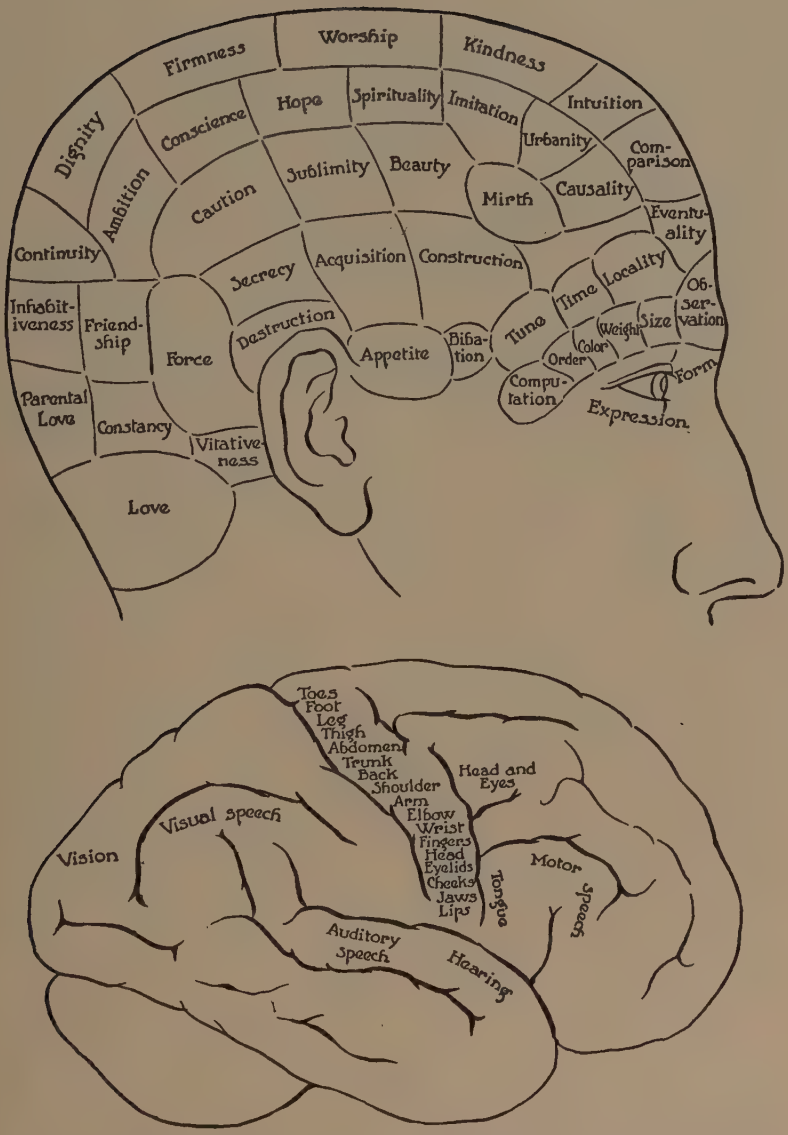

FIG. 55.—Upper part shows a typical phrenological map (Fowler); lower part shows the human cerebral hemisphere upon which the functional areas of the cortex are indicated. (Adapted from Herrick.)

Figure 55 presents a typical brain-function outline of the present day.[17] Brain localization as now accepted is very tentative. The latest findings place emphasis increasingly upon the quantity of nervous tissue available and stress the reaction of the brain as a whole, even in simple mental functions. The sense of color was localized by the phrenologist immediately behind the eye, whereas we now know that the visual area is located in the occipital lobe. In this instance the phrenologists were as far wrong geographically as it was possible to be. And yet their placement of the color sense immediately behind the eye must have seemed reasonable enough at the time as an illustration of the principle that nature is always frugal and economical. The mental faculty of "worship," which we now recognize only as a very general label applicable to a variety of attitudes rather than as a unitary mental function, was localized in what corresponds to the pre-Rolandic area. As a matter of fact, the function of this particular area is wholly motor and controls such activities as wiggling the toes. (Compare the upper and lower parts of Figure 55.) Readers versed in modern neurology will be amused at many similar grotesque errors committed by the phrenologists. That there could be any point-for-point correspondence between unevennesses on the skull and similar variations in the contour of the brain likewise seems most fanciful to modern brain specialists. The type of mental analysis indulged in by Gall, Spurzheim, and their successors is known as faculty psychology, long since discredited by experimental psychology.

As an example of the sort of evidence marshaled in behalf of phrenology may be mentioned an investigation of 160 deaf children undertaken by Fowler. He believed that "causality" and "comparison of ideas" would be the two mental traits developed to an unusual degree in the deaf because their physical handicap would necessitate the compensatory development of

[17] C. Judson Herrick. An introduction to neurology. W. B. Saunders Co., Philadelphia. 1916. p. 283.

reflective thinking in the absence of normal opportunities for social contacts. When the heads of deaf children were examined, we are seriously told that in truth their foreheads bulged to an unusual degree exactly over those brain areas in which "causality" and "comparison of ideas" are localized. Here is the example par excellence of "The wish is father to the thought," since psychological testing of the deaf has established the fact that they are most seriously handicapped in language ability, surely a basic requisite for "comparison of ideas," whatever the phrase may mean.[18]

A chief phrenological tenet holds that the greater the intellect, the larger the brain and, hence, the larger the skull. This belief in a close relationship between size of skull and intellect was so widespread in scientific circles that Karl Pearson, as recently as 1906, undertook to put the belief to a crucial test.[19] He collected data for some 4,500 twelve-year-old boys and girls and for 1,010 Cambridge University students, showing for each subject certain cranial measurements together with his intellectual standing as determined by teachers' estimates and scholastic grades. When cranial measurements were correlated with intellectual ability, the absence of a close relationship was immediately apparent as may be seen from Table 22. As Pearson points out, these correlations do indicate the existence of a slight but sensible relation between size of head and intelligence. The relationship is so slight, however, that it is impossible to make use of such a correlation in attempting to predict the intelligence of any individual person on the basis of head measurements. A quotation from Pearson will emphasize the fact that even up to most recent times the phrenological belief concerning head size and intelligence still had a foothold in

[18] Rudolf Pintner and Donald G. Paterson. The Binet Scale and the deaf child. J. Educ. Psychol., 6: 201-211. April, 1915. Also, A measurement of the language ability of deaf children. Psychol. Rev., 23: 413-436. November, 1916. Also, The ability of deaf and hearing children to follow printed directions. Ped. Sem., 23: 477-497. December, 1916.

[19] Karl Pearson. Relationship of intelligence to size and shape of the head and other mental and physical characters. Biometrika, 5: 105-146. 1906.

scientific circles: "It is impossible to use head size as a basis for judgment as to intelligence. Of course, all this is merely stating in other words what is obvious to the biometrician when he finds a low correlation, but possibly, although I am hardly hopeful, it may help convince the anatomist and old school anthropologist that head measurements are not of real

TABLE 22

Correlation Ratio between Certain Cranial Measurements and Estimates of Intelligence

(After Pearson, '06)

Correlation Ratio between Intelligence and	1,011 Cambridge Univ. Graduates	2,290 Boys, Age 12 Yrs.	2,165 Girls, Age 12 Yrs.
Cephalic index	−.06±.02	−.04±.01	+.07±.01
Length of head	+.11±.02	+.14±.01	+.08±.01
Breadth of head	+.10±.02	+.11±.01	+.11±.01
Height of head	.....	+.07±.01	+.06±.01

service as intelligence tests" (p. 122). The lack of significance attaching to head measurements can be more fully realized when we note in this same study that eye color and hair color are related to intelligence as closely as are head diameters. We may conclude that head measurements are related positively to intellect to only a very slight extent—no more closely, in fact, than is eye color or hair color.

4. Logical Fallacies Underlying Phrenological and Physiognomic Beliefs

To the psychologist these systems of character analysis are of interest, not so much from the standpoint of verification or refutation, but rather from the point of view of the psychological and logical factors underlying such false beliefs. It is quite evident that belief in physical and psychological discontinuity is implicit in much, if not all, of the thinking of the character

analyst. That is, he tends to pigeonhole mankind into distinct physical and mental classes or types as if physical traits and mental traits exist in discrete steps or grades. As a matter of fact, biometric research regarding the distribution of human traits, whether physical or mental, clearly shows all such traits to be continuous, for the most part distributed in a manner approximating the normal probability curve. This belief that traits are discontinuous, and that their interrelation is relatively simple, admirably illustrates the fallacy of false simplicity.

Error due to the unbridled functioning of imagination is clearly demonstrated in the detailed phrenological maps that were worked out so meticulously by Gall and his followers. Localizing traits in particular areas of the brain in the absence. of a solid basis of observable facts illustrates the rôle of pure fancy. Such fallacious induction is characteristic of those who fail to secure data from experimentally controlled observation and to utilize quantitative methods of analysis. The fallacy of the particular case, in which the dramatic character of the isolated instance cannot be resisted, is likewise exhibited over and over again in this literature. It appears as a tendency to collect cases to prove a point in utter disregard of all negative instances. Here is William James's "will to believe" operating with a vengeance. It seems as though there is a strong urge to accept the idea of some sort of harmonious adjustment of inner function and outer structure.

This failure of character analysts systematically to verify their pronouncements through follow-up studies is natural in view of the confidence most people have in their own judgments of human character. The fact that the degree of confidence we have in passing judgment upon the other fellow is no guarantee of the correctness of this judgment was forcibly brought home to the writer some years ago when making psychological examinations of all new patients entering the Ohio Institution for the Feeble-Minded. On a particular morning a beautiful child, apparently five or six years of age, was brought

into the psychological laboratory for examination. Large, bright brown eyes, fine black hair neatly combed, beautiful olive complexion, together with a freshly laundered, pretty dress combined to produce an immediate judgment—"Somebody has made a horrible blunder; surely this child has no business being in a feeble-minded school." An animated and attractive smile on the girl's face converted this impulsive judgment into a profound conviction. Had the writer seen this girl in a street car or on the playground, he would have immediately concluded that she was an unusually bright youngster. Furthermore, if further opportunity for observing this child in action had not been granted then, this passing judgment, rendered so confidently, would have remained unchallenged. To obtain a psychological rating, however, it was necessary to proceed with the examination.

When the child was asked, "What is your name?" there was no response. The thought flashed through my mind, "This child is deaf—someone has failed to distinguish between deafness and feeble-mindedness." So I stepped behind her and clapped my hands. She responded by turning toward the noise. Then I surmised that she was suffering from some sort of speech difficulty. This judgment called for the abandonment of the usual Binet tests and for resort to non-language performance tests.[20] One of the simplest form boards was placed before her with the simple gestures that usually suffice to bring satisfactory response even from an untutored deaf child. Her response was woefully inadequate—aimless fumbling with the blocks. It then for the first time dawned upon me that in truth she was seriously deficient mentally. The reader can imagine my surprise when I gave her the choice of a piece of wood and a piece of milk chocolate to find that she chose the wood, put it into her mouth, and attempted to chew it up. I finally wrapped a piece of chocolate in a piece of paper and offered it

[20] Rudolf Pintner and Donald G. Paterson. A scale of performance tests. D. Appleton & Co., New York. 1917. p. 1-218.

to her. She grabbed it, put it in her mouth, paper and all, and proceeded to eat it, thereby demonstrating an incapacity even to eat discriminatingly. The diagnosis was "idiot" with a mental level of less than one year.

On that same day another patient was brought into the laboratory, assisted solicitously by a nurse because of great difficulty in walking. This patient, a girl of fifteen, was partially paralyzed and succeeded in dragging herself to a chair beside my desk only with the greatest difficulty. Her skin was rough, dark, and leathery in appearance. Her eyes were crossed, adding to a marked distortion of the face through asymmetry of facial contour. When asked her name, she replied slowly and with evident difficulty in manipulating her tongue, jaws, and lips. I immediately judged her to be a low-grade imbecile and hence began the examination with tests suitable for the ordinary three- or four-year-old child.

To the first question, "Point to your ears," she failed to respond. Apparently my first impression was fully confirmed. But there was something in her expression that indicated displeasure. The examination was therefore temporarily discontinued pending re-establishment of favorable rapport. I asked her where she lived and to my surprise she answered by giving her street address as well as the name of her home town. I then asked her if she had any brothers or sisters, and she replied by giving me a complete account of the members of her family. All of this was volunteered, although with great difficulty in speaking. It dawned upon me at last that I had previously insulted her intelligence by asking her to do such an absurd and easy thing as pointing to her ears. I then renewed the examination by asking some of the more difficult questions in the Binet Scale, and she answered them in a most satisfactory manner. When the examination was finally over and her mental age was computed, I discovered that she had earned one of the highest ratings of any inmate I had examined. My first judgment was wholly in error.

Such experiences as these make the psychologist distrust his ability to estimate intelligence from appearance or superficial observation. Binet recognized this limitation upon most judgments of intelligence, and he therefore proceeded to develop objective, standardized tests to replace impressionistic estimates. The availability of such a device as a mental test makes it possible for the psychologist to check the correctness of first impressions, and since so often first impressions are found to be widely erroneous, it is natural for psychologists to hold that the claims of character analysts should be heavily discounted, especially when it appears that they have neglected to develop any satisfactory techniques for detecting or recording instances of false judgment.

This preceding review of non-scientific and pseudo-scientific notions regarding an intimate relationship between physical and mental characters has been necessary in order that we may approach the scientific studies of the problem properly inoculated with an attitude of "suspended judgment." Such negative evidence as has emerged from the above considerations need not close our eyes to satisfactory proof, although it certainly constitutes an argument for extreme caution.

III. SCIENTIFIC STUDIES OF PHYSIQUE IN RELATION TO MENTAL TRAITS

1. Structural Characteristics—Height and Weight

From the time of Galton's observations that men of genius tend to be above the average in height and weight down to the present, many studies have been reported asserting or denying a close correlation between these two structural characteristics on the one hand and intellect on the other. Galton's preeminent position as one of the founders of modern biometry adds to his views the weight of authority. His reported observations are so interesting as to warrant the following extended quotation:

There is a prevalent belief that men of genius are unhealthy, puny beings—all brain and no muscle—weak-sighted, and generally of poor

constitutions. I think most of my readers would be surprised at the stature and physical frames of the heroes of history who fill my pages, if they could be assembled together in a hall. I would undertake to pick out of any group of them, even out of that of the Divines, an "eleven" who should compete in any physical feats whatever, against similar selections from groups of twice or thrice their numbers, taken at haphazard from equally well-fed classes. In the notes I made, previous to writing this book, I had begun to make memoranda of the physical gifts of my heroes, and regret now, that I did not continue the plan, but there is even almost enough printed in the appendices to warrant my assertion. I do not deny that many men of extraordinary mental gifts have had wretched constitutions, but deny them to be an essential or even the usual accompaniment. University facts are as good as any others to serve as examples, so I will mention that both high wranglers and high classics have been frequently the first oarsmen of their years. The Hon. George Denman, who was senior classic in 1842, was the stroke of the University crew. Sir William Thompson, the second wrangler in 1845, won the sculls. In the very first boat-race between the two Universities, three men who afterwards became bishops rowed in one of the contending boats, and another rowed in the other. It is the second and third-rate students who are usually weakly. *A collection of living magnates in various branches of intellectual achievement is always a feast to my eyes; being as they are, such massive, vigorous, capable-looking animals.* [Italics mine.][21]

Galton's observations admittedly were unsatisfactory to some degree in view of the lack of precise comparative data. More recently, Gowin supplied height and weight data for a group of 1,037 American executives—governors, senators, mayors, university presidents, bishops, merchants, manufacturers, and presidents of insurance and railroad companies.[22] The average height is reported as 71.4 inches and the average weight as 181.1 pounds—figures obviously above the average for the population at large (the average height of one million U. S. Army recruits is 67.5 inches). An interesting and rather significant comparison of the average height and weight of what we may

[21] Francis Galton. Hereditary genius. Macmillan & Co., Ltd., London. 1st ed., 1869. Reprinted, 1925. p. 321.

[22] E. B. Gowin. The selection and training of the business executive. The Macmillan Co., New York. 1918. p. 85.

designate as major and minor executives within each of a series of similar lines of work is also given by Gowin. A summary of these comparisons is shown in Table 23. In every case the difference is in the same direction, and hence may be accepted as indicative of a definite trend. Although Gowin places great stress upon the findings as demonstrating the importance of

TABLE 23

COMPARISON OF MAJOR AND MINOR EXECUTIVES WITH RESPECT TO AVERAGE HEIGHT AND AVERAGE WEIGHT

(After Gowin)

CLASS	AVERAGE HEIGHT	DIFFERENCE	AVERAGE WEIGHT	DIFFERENCE
Bishop	70.6	1.8	176.4	17.0
Preachers in small towns	68.8		159.4	
University presidents	70.8	1.2	181.6	17.6
Presidents of small colleges	69.6		164.0	
City school superintendents	70.4	0.7	178.6	21.0
Principals in small towns	69.7		157.6	
Salesmanagers	70.1	1.1	182.8	25.8
Salesmen	69.1		157.0	
Presidents of railroad companies	70.9	1.5	186.3	31.7
Station agents in towns of 500 population	69.4		154.6	

height and weight factors in the personalities of the more successful executive, we must remember that the data were collected by the questionnaire method, which sometimes produces biased results through lack of random sampling in returns. Of course if people in general *believe* that large stature adds to the prestige of a man in power, it would follow that governing boards would tend to select "big" men for important executive positions. For these reasons we must examine the evidence

that height and weight are significant indications of intelligence in quantitative studies of these traits as they exist in a random, unselected sample of a total population. It may be that data on school children representative of all social and economic classes in a given community would afford a better opportunity for studying this question than would studies of particular groups of adults in universities, in executive positions, or in any other positions of outstanding importance.

Another reason for centering attention upon children is to be found in the phenomenon of growth itself. During childhood physical growth and mental growth proceed concurrently and at a rapid rate. The fact that tallness or shortness is a surprisingly constant characteristic for individual children and that brightness or dullness is likewise surprisingly constant for the individual child, in spite of a rapid acceleration in both respects, makes it eminently worth while to study the relationship between stature and intelligence during the period of childhood. Mental growth curves and physical growth curves for individual children are so similar in appearance as to suggest a most intimate relationship between these two phases of growth. Figures 56 and 57 emphasize this point in a striking manner.[23]

In the early 1890's the importance of studying the relationship between physical and mental development among children was clearly recognized. It so happens that the original study by Porter of 33,500 St. Louis school children seemed to afford a sound basis for concluding that stature and weight are both closely related to intelligence.[24] He used age-grade location in school as a criterion of brightness and dullness. That is, the nine-year-old in the first grade is assumed to be mentally retarded, whereas the nine-year-old in the fourth grade is assumed to be mentally accelerated. When tables showing aver-

[23] B. T. Baldwin and L. I. Stecher. Mental growth curve of normal and superior children. University of Iowa Studies in Child Welfare, 2: 1-61. January, 1922.

[24] W. T. Porter. The physical basis of precocity and dullness. Transactions of the Academy of Science of St. Louis, 6: 161-181. 1895.

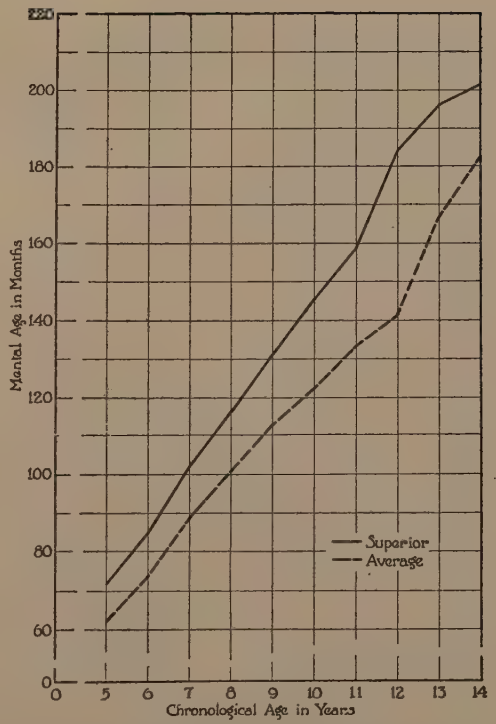

FIG. 56.—Mental growth curves for mentally superior and average girls. (Baldwin and Stecher.)

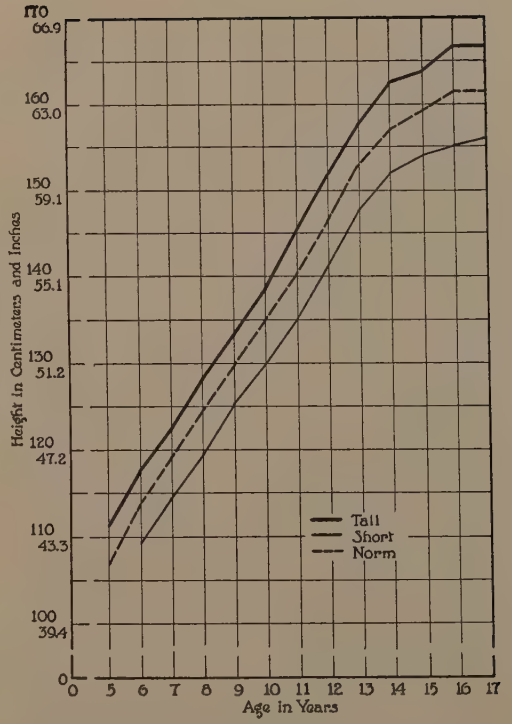

FIG. 57.—Physical growth curves in height for tall, average, and short girls. (Baldwin and Stecher.)

age height and average weight for the two sexes separately for each age in each grade were constructed, the relationship between physical development and mental development appeared to be quite definite. For example, the median weights for nine-year-old boys in the various grades were as follows: 55.87 for those in grade I; 57.64 for grade II; 59.66 for grade III; and 61.75 for grade IV. It is clear that the brighter nine-year-old boys (in grades III and IV) are on the average distinctly heavier than the duller nine-year-old boys (in grades I and II). Porter believed that these data established a physical basis of precocity and dullness.

Many workers, employing this same method of analysis, have repeated Porter's investigations, always confirming his results. Unfortunately, demonstration of a trend in averages was interpreted as indicating a *close* relationship between physical development and mental development, whereas the method of averages could, at best, indicate nothing more than the presence of a trend for children in the mass.

We now know that if the modern method of correlation had been available when Porter undertook his investigation, its use would have demonstrated the presence of only a slight relationship. Had such a conclusion been reached in this first important study, subsequent investigators would not have perpetuated the misleading exaggeration that has persisted until within the past few years.

It so happens that Porter, for illustrative purposes, presented a small fragment of his data in the form of what we now designate as a correlation scatter diagram. These data (reproduced as Table 24) show the grade location of each of 2,169 nine-year-old boys in relation to weight. The writer computed the Pearson coefficient of correlation for this scatter diagram, obtaining an r of $+0.06 \pm 0.01$. If this be taken as the probable amount of relationship present in Porter's data as a whole, it is so slight as to invalidate the great emphasis placed by him and

by many subsequent investigators upon physical status as a basic factor conditioning mental development.

For those unfamiliar with correlational data the result just reported must be surprising, especially when it is remembered that the averages for nine-year-old boys in the various school

TABLE 24

SCATTER DIAGRAM SHOWING RELATION BETWEEN WEIGHT AND GRADE LOCATION OF 2,169 BOYS, AGED 9

(After Porter. p. 163)

WEIGHT IN POUNDS	SCHOOL GRADE					TOTAL
	I	II	III	IV	V	
86–90	..	2	..	..	..	2
81–85	1	2	3	..	..	6
76–80	..	10	8	2	..	20
71–75	8	24	15	4	1	52
66–70	17	93	36	6	..	152
61–65	99	236	90	13	1	439
56–60	155	334	91	10	..	590
51–55	169	343	81	6	1	600
46–50	86	122	21	3	..	232
41–45	29	25	5	..	..	59
36–40	5	1	5	..	..	11
31–35	1	3	2	..	..	6
Total	570	1195	357	44	3	2169
Median	55.87	57.64	59.66	61.75	65.00	57.75

$r = +.06 \pm .014$

grades reported four paragraphs back were derived from the data that are given in Table 24. Of course by restricting one's attention to the *averages alone,* the trend appears to be quite pronounced, but we have long since, in dealing with measurements of mankind in the mass, discovered that we must scrutinize our data with respect to variability as well as central

tendency. As may be seen from Table 24, the overlapping is tremendous. The distribution of weight for each of the grades is very similar.

Without boring the reader with detailed presentations and criticisms of findings of such workers as Gilbert, Boas and West, De Busk, Smedley, Arnold, Stewart, Pyle, Baldwin, and Brooks, we may cite as evidence for the position of this paper with respect to height and weight, the work of Murdock and Sullivan in Honolulu, who adopted an exceptionally satisfactory scientific approach to the problem.[25]

Their investigation differs chiefly from the work of predecessors in utilizing on a large scale minutely graduated measures of intelligence. Standard intelligence tests such as the Otis Primary Test for grades I-III, the National Intelligence Test for grades III-IX, and the Terman Group Test of Mental Ability for grades IX-XII were used—all tests being administered by Katharine Murdock, who was serving as school psychologist. The physical measurements were made by Louis R. Sullivan, anthropologist representing the American Museum of Natural History in New York. In a sense it is fortunate that the physical data and the mental data were obtained in entire independence of each other and for other purposes than that of correlating the two. The subjects were some 600 pupils of old American, British, German, or Scandinavian descent, constituting a "fairly homogeneous race group."

Scores on the mental tests were converted into *IQ*'s (intelligence quotients obtained by dividing mental age by chronological age) and in similar manner the absolute physical measures were converted into relative measures by expressing each as a quantitative deviation from the average of each age-sex group. Both techniques thus eliminate the age factor, permitting direct comparison for all subjects.

[25] K. Murdock and L. R. Sullivan. A contribution to the study of mental and physical measurements in normal children. Amer. Phys. Educ. Rev., 28: 209-215; 276-280; 328-330. 1923.

The main correlations emerging from their work are as follows:

r between weight and $IQ = +0.16 \pm 0.03$ $(N = 595)$,
r between height and $IQ = +0.14 \pm 0.03$ $(N = 597)$.

There is thus shown to be a slight positive correlation between height, weight, and intelligence. Recomputation of the correlation between weight and intelligence for boys and girls separately did not reveal any effect from lumping the two sexes together in the original computations.

The precarious basis for individual predictions afforded by such slight correlations as have been cited is also present even when we attempt the far easier task of group predictions. It will be remembered that Professor Jackson, in the present series of lectures, cited comparative figures on height, weight, etc., for Yale University students and for University of Minnesota students. His data show the latter to be superior, on the average, to the former in a series of physical measurements. Presumably such physical superiority should indicate mental superiority as well. But available facts indicate quite the reverse. The median score of Yale freshmen on the Army Alpha Intelligence Test was reported as being 159.5 [26] (slightly higher than the median score of 157 made by Ohio State University graduate students!), whereas the median score of University of Minnesota freshman men was reported as being 129 on the same test.[27] Approximately 89 per cent of the Yale freshmen exceeded the median Minnesota student. Only 11 per cent of the Yale freshmen made a score as low as, or lower than, the median for Minnesota freshmen. These figures bear eloquent testimony in behalf of the success of Yale's selective admission scheme in recruiting mentally superior freshmen. The results are in striking contrast to those secured by the admission plan

[26] J. E. Anderson. Intelligence tests of Yale freshmen. School and Soc., 11: 417-420. 1920.

[27] L. M. Terman. Intelligence tests in colleges and universities. School and Soc., 13: 481-494. 1921.

of a state university. But Yale's policy definitely fails to secure physical superiority as well. Here is convincing evidence of the almost complete independent variability of physical and mental traits. The two are so slightly related that selective factors may easily operate to produce two contrasting mentality groups that differ physically in the reverse direction.

We may summarize the general trend of results of all the more important investigations by stating that a slight positive correlation seems to exist between physical development as indicated by height or weight and mental development. From one point of view, we would emphasize the fact that the relationship is definitely positive even though slight. From the point of view of the exaggerated notions, which have been current in the past and which exist even at the present time, it would be well to emphasize the fact that physical status and mental status are to a great extent independent of one another. That is, knowing a child's height or weight enables you to predict his mental capacity with an accuracy only a little better than a chance guess.

2. Anatomical Age and Mental Age

Closely following upon Alfred Binet's brilliant discovery of the possibility of measuring mental growth in terms of mental age, a series of American studies introduced a similar concept in regard to physical growth, namely, anatomical age. Scientific workers interested in child development quickly recognized the possibility of an intimate connection between mental age and anatomical age, and a number of research studies undertook to demonstrate this relationship.

Rotch, in a series of papers published from 1905 to 1910, described investigations of skeletal development designed to measure stages in the ossification of the eight carpal bones in the wrist. An excellent summary of this work is to be found in Woodrow's *Brightness and Dullness in Children*.[28] Rotch was

[28] H. Woodrow. Brightness and dullness in children. Chap. VI. Anatomical Age. J. B. Lippincott Co., Philadelphia. 1919. p. 97-122.

able by means of X-ray photographs to discriminate thirteen typical stages of skeletal development. The series of X-ray pictures affords a sort of standard developmental scale whereby from the photograph of any given child's wrist bones its stage of development might be inferred. In Figure 58 are reproduced three of the original photographs used by Rotch in his scale.

In vigorously defending the thesis that anatomical age and mental age are intimately interrelated, Rotch asserted that in cases where there is delayed mental development there is delayed skeletal development as well. Illustrative cases are cited in proof.

It is clear from the work of Rotch and others that marked individual differences in rate of skeletal development exist, just as there are marked individual differences in rate of mental development. The crucial question concerns the extent to which these two types of growth actually parallel each other in the individual child.

The work of the late Bird T. Baldwin [29] and of Woodrow and Lowell [30] suggested that the relationship was far less close than Rotch had supposed. Three further elaborate studies from the laboratories of Harvard,[31] Chicago,[32] and Columbia Universities [33] appeared almost simultaneously, pointing most definitely to an absence of any very close connection.

Because of the comprehensive character of Gates's investigation we may select his presentation as typical of the general findings regarding the intellectual significance of variations in

[29] Baldwin and Stecher. *Op. cit.* p. 56-58.

[30] F. Lowell and H. Woodrow. Some data on anatomical age and its relation to intelligence. Ped. Sem., 29: 1-15. 1922.

[31] D. A. Prescott. The determination of anatomical age in school children and its relation to mental development. Harvard Monographs in Education, Cambridge. 1923. Series 1, No. 5.

[32] F. N. Freeman and T. M. Carter. A new measure of the development of the carpal bones and its relationship to physical and mental development. J. Educ. Psychol., 15: 257-270. 1924.

[33] A. I. Gates. The nature and educational significance of physical status and of mental, physiological, social, and emotional maturity. J. Educ. Psychol., 15: 329-358. 1924.

a. Girl, three and one-half years old. *b. Girl, six years old.* *c. Girl, twelve and three-quarters years old.*

FIG. 58.—X-ray pictures showing three of the thirteen stages of anatomical development as determined by Dr. T. M. Rotch. (From T. M. Rotch, M.D. A study of the development of the bones in childhood by the Roentgen method. Transactions of the Association of American Physicians, 24:603-624. 1909.)

anatomical age. Indeed, it is Gates's work that permits us, for the first time, to portray the intercorrelations of the various measures that have been proposed as suitable indices of physical development. Furthermore, his work throws light on the correlation between these several physical indices and mental, emotional, social, and educational maturity ratings. Although his study involved only 115 pupils at the fourth-grade level and in the kindergarten, nevertheless the age factor was so well controlled through experimental selection and partial correlation technique that we may accept his results with unusual confidence in their validity.

The principal correlations are presented in Table 25. X-ray pictures of wrist-bone development correlates with Stanford-Binet mental age to the extent of +.11. It correlates with the other maturity indices only slightly more. Indeed the correlation between X-rays and physical vigor is only +.15. The conclusion of this study, supported by the other studies mentioned, is that the correlation between anatomical age and mental age or any other feature of mental, emotional, or social development is definitely positive but very, very slight. Not only is there an absence of appreciable relationship between wrist-bone ossification and mental age but also there is an equally impressive absence of marked relationship between any of the other six physical traits and mental age.

It is rather astonishing to discover from this table of correlations that no single physical measurement yields what might be termed a reasonably high positive correlation with physical vigor. If we assume that the physical vigor ratings are highly reliable and valid—and there is every reason to believe that they do faithfully portray the physical efficiency of the children —then what are we to say about the relatively low correlation between each of the physical traits and vigor ratings? Implicit in the whole literature on physical development is the assumption that any one physical trait is as good an index of development as any other. This assumption is based in turn upon the

assumption that all phases of physical development are closely interrelated, hence any one may be used as a suitable index of physical status taken as a whole. Now, if these assumptions are correct, we must conclude that physical vigor, stamina, and efficiency in participating in day-by-day school activities are not conditioned to an appreciable extent by such physical factors as skeletal status, chest development, lung or vital capacity, strength of grip, or nutritional status. Such a conclusion would

TABLE 25

COEFFICIENTS OF CORRELATION BETWEEN PHYSICAL TRAITS AND VARIOUS MATURITY INDICES

(After Gates)

PHYSICAL TRAITS	THE VARIOUS MATURITY INDICES *						
	Stanford-Binet *MA*	Mental Maturity	Social Maturity	Educ. Maturity	Educ. Achievement	Emotional Maturity	Physical Vigor
X-rays of wrist bones†	.11	.15	.24	.15	.16	.20	.15
Height	.06	.11	.11	.07	.01	.15	.18
Weight	.10	.13	.09	.17	.07	.17	.25
Chest girth	.09	.09	.15	.14	.03	.17	.19
Lung capacity	.09	.09	.12	.06	.00	.11	.22
Grip	.06	.07	.08	.15	.15	.05	.31
Nutritional status ‡	.13	.15	.18	.17	.15	.15	.37

NOTE: Each r is the average of four r's computed for each of four homogeneous sex and school groups, in each case age being held constant. N=115.

* Mental maturity = teacher's estimates of common sense, critical attitude, initiative, perseverance, and responsibility in mental activities. Social maturity = teacher's estimates of responsibilty for own acts, property, and hygiene; and cooperation, leadership, and respect for law and order. Educational maturity = teacher's estimates of school success. Educational achievement = objective, standardized subject-matter test scores. Emotional maturity = teacher's estimates of presence or absence of excessive emotionality, proper responsiveness, evenness of responsiveness, and emotional maturity versus babyishness. Physical vigor = teacher's estimates of health, vitality, stamina, and efficiency in the day-by-day school activities.

† X-rays taken by Department of Roentgenology of the Vanderbilt Clinic. Pictures were taken at exact natural size and were measured by a planimeter permitting computation of the ratio of ossification of wrist bones to total wrist bone area.

‡ Actual weight subtracted from the norm as found in the Thomas D. Wood Height and Weight Table.

be quite out of line with our notions of the physical determinants of vigor and stamina.

The explanation of this unfamiliar picture is of the utmost importance to pediatricians, child hygienists, directors of physical education, and others charged with responsibility for the physical welfare of children. As Gates points out, the true explanation lies in the simple fact that these physical traits are not closely related one to the other, and hence no one physical feature is an adequate index of either physical status or physical vigor. An adequate index would require a combination of several aspects of physical development. This is shown most clearly by the fact that when these physical measurements were properly weighted and combined by multiple correlation technique into a single index of physical development, the index obtained correlated to the extent of +.61 with the physical vigor ratings.

The above explanation provides us with definite and new insights into developmental problems, demonstrating as it does that physical growth is specialized and has many phases or aspects, no one of which adequately portrays the physical fitness of the child. This conclusion suggests the urgent need for an extensive cooperative research program designed to explore thoroughly the possibility of measuring physical vigor or stamina through utilization of every conceivable physical test (including such tests of incipient psychasthenia and neurasthenia as may be perfected) and through proper combinations of them to derive a single index of the greatest possible validity. Here is a pressing problem that will require the combined services of anthropometrists, pediatricians, and biometricians, especially those who have become expert "test statisticians," if satisfactory results are to be secured.[34]

[34] Gates suggests that height, weight, and ossification ratio should *not* be combined since they are too closely interrelated. A better battery of physical fitness tests would be nutritional status, grip, and weight; or nutrition, lung capacity, and height. The best results are attained when tests are chosen that correlate more closely with the criterion of physical fitness than they do with each other.

To go back now to the relation between these physical traits and mental development. Since multiple correlation technique applied to the physical measurements yielded a physical index that correlated +.61 with physical vigor ratings, it might well be suspected that when these same traits were properly weighted and combined they would thereupon yield a fairly high correlation with mental age. But when Gates attempted this, the maximum correlation turned out to be +.21. In other words, no method of statistically manipulating the physical measurements will bring about appreciable correlation between physique and intellect. We may conclude, therefore, that physical development and mental development are to a large extent independently variable, mental growth proceeding in relative independence of physical factors. However, this conclusion must not blind us to the fact that there is a slight positive correlation between the two, demonstrable for children in the mass.

3. Body Build and Intelligence

Interest in body build as a conditioning factor in disease, temperament, and intellect has long been manifested. Even Hippocrates differentiated between the "habitus apoplecticus" and the "habitus phthisicus." Data from Italy were cited in a preceding lecture by Professor Jackson indicating that there is a demonstrated susceptibility of these two body types (the stout vs. the thin) to apoplexy and circulatory disturbances, on the one hand, and to tuberculosis, on the other. More recently, Viola and also Naccarati describe the "macrosplanchnic type" in which the trunk is proportionately larger than the extremities. The "microsplanchnic" has extremities predominating over the trunk, while in the "normosplanchnic" the trunk and extremities are harmoniously developed. Sigaud emphasizes the "digestive," "muscular," "respiratory," and the "cerebral" body types. Mills recognizes the "hypersthenic," the "sthenic," and the "asthenic" types. And Kretschmer differentiates between

the "pyknic" type exhibiting a tendency toward rotundity with a barrel-shaped trunk and relatively short extremities, the "asthenic" type in which the extremities are relatively long in proportion to a relatively small trunk, the "athletic" type in which the various parts of the body are well developed and in proper proportions, and a "dysplastic" type composed of those not fitting into any of the three main classes. As Wertheimer and Hesketh point out, there is a marked similarity between these various schemes of body-type classification in spite of differences in terminology.[35]

Of immediate concern to the psychologist are Naccarati's researches designed to demonstrate a morphological basis for intellect.[36] Believing that no single anthropometric measurement, such as height, would solve the problem of the physical correlate of intelligence, he proposed to utilize a complicated morphological index that would be definitely related to intelligence since it is a composite of many elementary physical traits. This morphological index is the ratio of the length of the limbs to the volume of the trunk

$$\left(MI = \frac{\text{length of extremities}}{\text{trunk volume}}\right).$$

A high index is indicative of microsplanchny and a low index of macrosplanchny. This scheme recognizes continuity of variation from the one extreme to the other. In the absence of all of the necessary measurements, Naccarati authorized, and indeed chiefly employed in his own work, a simple substitute for the *MI*, namely, the height-weight ratio $\left(\frac{\text{height}}{\text{weight}}\right)$.

Rather elaborate reasoning based on certain physiological facts primarily concerned with the functions of the endocrine glands led Naccarati to assume that microsplanchnics are more

[35] F. I. Wertheimer and F. E. Hesketh. The significance of the physical constitution in mental disease. Medicine, 5: 375-463. November, 1926.

[36] S. Naccarati. Morphologic aspect of intelligence. Arch. Psychol., No. 45. August, 1921.

intelligent than macrosplanchnics. In order to verify this thesis, he conducted a number of experiments with Columbia University students correlating their indices of body build with scores on various standard intelligence tests. In all, thirteen coefficients of correlation between these two factors were reported in his various papers, the average being +0.26. Such a value would seem to indicate that there is a closer relation between body build and intellect than between intelligence and any isolated physical trait, such as height, weight, or ossification ratio. However, the experimental groups yielding these correlations in several instances were too small to preclude the possible effects of chance in producing moderately high correlations. Furthermore, these experimental groups sometimes contained both men and women, a somewhat questionable procedure since there are marked sex differences in body build. A further complicating factor may have been the inclusion of Jewish students in disproportionately large numbers. If Jewish students tend to be brighter than non-Jewish students and if they also tend toward microsplanchny to a greater extent, the result would be a correlation spuriously raised because of a racial factor. One of my graduate students is now investigating this possibility.

Five attempts to verify Naccarati's results were promptly made by psychologists—Heidbreder, Stalnaker, Sheldon, Garrett and Kellogg, and Sommerville. They all produced negative results. Heidbreder's experiment is perhaps the most significant, since her attempt at verification was based upon 1,000 white, native-born American students, with adequate controls as regards sex, reliability and validity of intelligence tests employed, and careful physical measurements of height and weight. The mental and morphological heterogeneity of her subjects (freshmen in the University of Minnesota) as compared with the Columbia University subjects should of course yield higher correlations than Naccarati's, provided there is as

great a relationship between the height-weight ratio and intellect as he announced.[37] But the actual correlations approximate zero. In a similar manner, the other four attempts to verify Naccarati's conclusions culminated in negative results, the trend of the correlations pointing to a very slight positive correlation.

Just as with height, weight, and anatomical age, so with morphological index, the experimental evidence warrants the view, at present, that physical status and mental status are largely independent of one another. From the viewpoint of man in the mass, there is a definite, though slight, correlation between physical development and mental development. From the point of view of individuals, the connection between physical characters and intellectual traits is so slight as to make it quite impossible in any given case to predict mental status, knowing physical status, and vice versâ. In other words, so far as these researches go, we have as yet to discover a physical basis for solving this twentieth-century and empirical "mind-body" problem.

4. Body Build and Temperament

We might expect, a priori, to find that body build and temperamental characteristics are definitely associated, since endocrinological investigations disclose an intimate connection between the glands of internal secretion and emotional responses on the one hand and ductless gland functioning and physical growth on the other. Draper is the most prominent champion of this view in America, exploiting the fact of these relationships primarily in connection with disease entities.[38] Kretschmer, in Germany, working with psychopathic subjects, has evolved a most elaborate system, developing his doctrine of

[37] E. Heidbreder. Intelligence and the height-weight ratio. J. Appl. Psychol., 10: 52-62. March, 1926.

[38] George Draper. Human constitution. W. B. Saunders Co., Philadelphia. 1924. p. 1-345.

body type and temperamental disposition to the point where it can be applied to all mankind.[39] At least, so he claims.

Kretschmer's physical basis for classifying body types into asthenic, athletic, pyknic, and dysplastic groupings relies upon average measurements and verbal descriptions of height, weight, shoulder width, chest girth, leg length, and circumference of stomach, hips, forearm, hand, and calf. These constitute the major differentiating criteria. In addition, the host of secondary criteria suggested include seven head and face measurements, quality and distribution of hair over the body, texture and color of skin, condition of various glands, and anomalies of the sex impulse. Although objective measurements are frequently cited, still the differentiation of types remains essentially subjective, involving a synthetic judgment composed of a host of detailed impressions. Indeed, the criteria are so numerous and so unstandardized that it is very doubtful whether or not two independent investigators, equally desirous of faithfully applying Kretschmer's scheme, would classify the same individuals into the same physical categories.

Kretschmer himself finds difficulty in applying his system consistently, as is shown by his employment of innumerable "mixed classifications" such as asthenic-athletic, pyknoid, asthenic-hypoplastic, asthenic-pyknic features present simultaneously in the same individual, pyknic mixture, dysplastic, uncataloguable forms, etc. All this reminds us of the image-type classification difficulties encountered in the early days of "type-thinking," which characterized an earlier school of psychologists.

There are additional reasons for believing that Kretschmer's methodology is unwieldy and scientifically unsatisfactory. We refer to the fact that when quantitative measurements are given they consist of mere averages, unsupported by measures of variability. Moreover, his data are not classified according

[39] E. Kretschmer. Physique and character. Translated by W. J. H. Sprott. Harcourt, Brace & Co., New York. 1925.

to age, sex, intelligence, and social status, which makes it impossible for other scientists to apply his method with assurance of comparable results. As the matter stands, Kretschmer's outline is definitely limited in application to material similar to that from which it was derived, namely 260 psychopathic cases springing from the Schwabian people in Germany.

TABLE 26

PERCENTAGE DISTRIBUTION OF 85 CIRCULARS (MANIC-DEPRESSIVE CASES) AND 175 SCHIZOPHRENICS (DEMENTIA PRAECOX CASES) ACCORDING TO PHYSICAL TYPE

(After Kretschmer)

PHYSICAL TYPE	CIRCULARS PER CENT	SCHIZOPHRENES PER CENT
Asthenic	4.7	46.3
Athletic	3.5	17.8
Asthenico-athletic mixed	2.3	6.3
Pyknic	68.2	1.2
Pyknic mixture	16.5	1.8
Dysplastic	0.0	18.9
Deformed and uncataloguable	4.7	7.5
Total	99.9	99.8

Kretschmer's unique contribution consists in an ingenious utilization of physical types in relation to the fundamental temperamental differences exhibited by the two contrasting groups of psychotic patients, namely circulars or manic-depressives, and schizophrenics or dementia praecox patients. At an early point in his discussion the relationship is shown by a classification according to body build of 85 circular cases and 175 schizophrenic cases. A percentage distribution has been computed by the writer and is shown in Table 26. A glance at the table reveals a concentration of the manic-depressives in the pyknic and pyknic mixture categories, 84.7 per cent being so classified. Although the dementia praecox patients are not so definitely

confined to the asthenic body build, nevertheless there is an unmistakably strong drift in that direction. The relative absence of schizophrenics in the pyknic and pyknic mixture classes is to be noted especially.

This proof of some sort of affinity between contrasting psychotic temperaments and contrasting body types leads Kretschmer to generalize beyond the limits of psychopathology by extending his theory to include normal personalities found in everyday life. In so doing he recognizes a transition from circular insanity, first to the cycloid temperament in which the patient exhibits mild excitements and depressions, and finally to the cyclothymic personality, normal and well adjusted to the ordinary demands of life. Similarly, from the pathological schizophrene we go to the schizoid, reflecting in milder degree the fundamental psychological traits of the true dementia-praecox patient, and then to the schizothyme, who is normal and well adjusted. The cycloid is sociable, genial, jolly, and yet easily depressed. The cyclothymic exhibits these same traits to a lesser degree. The schizoid, on the other hand, is unsociable, reserved, sensitive, indifferent, and silent. The normal schizothymic possesses these same traits to lesser degree. Thus contrasting body types characterizing the two fundamental pathological temperaments are asserted to be found definitely associated with corresponding contrasting temperaments in everyday life.

Confirmation of Kretschmer's theories is to be found in the work of Wertheimer and Hesketh although their investigation included such a small number of cases as to force suspension of judgment pending more extensive investigations by a variety of investigators.[40] There is urgent need for such additional studies with adequate statistical methods and careful controls to the end that manic-depressives and schizophrenes may be matched as regards age, sex, race, nationality, previous education, occupation, and social status. Verification of Kretschmer's

[40] Wertheimer and Hesketh. *Loc. cit.*

theories as they apply to normal personalities would be greatly facilitated were someone to invent a satisfactory scale for measuring cyclothymic and schizothymic temperamental characteristics. Here is a challenging opportunity of the utmost importance in developing the science of characterology in a new field of research.

The emphasis that Alfred Adler has placed upon physical deficiencies, "organ inferiority," as the physical basis for the genesis of feelings of inadequacy, which so frequently characterize the neurotic temperament, makes it appropriate for us to consider a recent attempt at verification of this concept in our own University.

Faterson, under the direction of Dr. E. Heidbreder and the writer,[41] made an extensive study of the Heidbreder Inferiority Attitude Self-Rating Scale. Among other things, she attempted to determine, for college students, the relationship between scores on the self-rating scale and the height-weight ratio and the presence or absence of certain physical defects.

Description of the construction of the scale, together with preliminary results, was published by Heidbreder in 1927.[42] The scale included 130 traits culled from the writings of Adler as being symptomatic of feelings of inferiority. Statistical analysis of self-ratings and associates' ratings for 268 college students showed the scale to contain a consistent set of traits. Those traits that proved to be most diagnostic are the very ones that theoretical considerations emphasize. A comparison of original ratings and re-ratings after a six weeks' interval shows the scale to be sufficiently reliable to warrant its use as a research instrument.

When self-ratings obtained from 673 freshman men were correlated with the height-weight ratio for these same men, a

[41] Hannah Fay Faterson. Some implications of the normal inferiority complex. A thesis submitted to the University of Minnesota graduate faculty in partial fulfilment of the requirement for the degree of Doctor of Philosophy. 1928.

[42] E. F. Heidbreder. The normal inferiority complex. J. Ab. and Soc. Psychol., 22: 243-258. October-December, 1927.

Pearson *r* of +.03 ±.03 was obtained. For 531 freshman women, a very slight but apparently definitely established positive correlation of +.11 ±.03 was found for the same set of measurements. Apparently there is a slight tendency for tall and thin women to rate themselves higher on the inferiority scale (as possessing feelings of inadequacy). No such tendency appears for the men. Neither does the fact of being undersized lead the undersized student to rate himself as possessing the inferiority attitude to any greater extent than do men students in general. It would seem as though body build as measured by the height-weight ratio is not an important factor conditioning the existence of inferiority attitudes.

When Faterson analyzed the medical examination records and compared the self-rating scores of those possessing various physical defects with the scores of those not possessing those defects, positive results emerged. Those possessing certain physical defects were found to have higher average self-rating scores than those without such defects.[48]

Believing with Adler that it is the *general* condition of being below par rather than any *particular* defect that is related to feelings of inferiority, Faterson proceeded to correlate "total defect scores" with the scale. For 680 men the Pearsonian *r* was +.16 ±.03 and for 549 women the *r* was +.24 ±.03. These positive correlations verify, in general, Adler's main contentions. This verification is especially significant since a demonstration of association between physical defects and feelings of inferiority is here made on the basis of "normal" subjects. Presumably the association would be even more pronounced were the Faterson-Heidbreder techniques applied to populations including a large number of extreme psychoneurotics. That the correlations found by Faterson are not higher need not surprise us when we realize that the self-rating scale is not a perfectly reliable nor perfectly valid measuring instru-

[48] One is reminded in this connection of Bacon's observation, "Whosoever hath anything fixed in his person that doth induce contempt, hath also a perpetual spur in himself to rescue and deliver himself from scorn."

ment. Moreover, since abnormal phenomena generally result from multiple causation, there is no reason to expect that the inferiority attitude would be conditioned solely by organic defects. That the relationship emerges to such a definitely established extent among "normal" subjects is of great importance, especially when we consider the monotonous trend of negative results revealed by our survey of empirical tests of asserted relationships between physical characters and mental traits.

It is perhaps also significant to find our first positive results emerging in the general field of physique and temperament. It is not improbable that this line of attack will prove more fruitful than attempts to find a physical basis for those aspects of behavior that are more definitely controlled by the central nervous system.

5. Physical Condition and Intelligence

Space limitations forbid more than brief reference to this important topic. Its importance arises from the prevalence of the view that the enormous range of individual differences in intellect among children and adults is to be explained in terms of differential opportunities for developing a strong physique. Our friends with strong leanings toward explanations in terms of environment have not failed to promulgate the doctrine that physiological impairment would necessarily have a deleterious effect upon normal intellectual development. Indeed, the presumption that malnutrition, diseased tonsils and adenoids, enlarged glands, dental caries and impacted teeth, etc., prevent normal mental growth is so strong that most investigators approach the problem, not with the idea of discovering whether or not such conditions adversely affect mental development, but rather to determine just how extensive is the havoc wrought by these deleterious influences.

However, negative results reported by David Heron from an application of the precise biometric techniques of the Galton-Pearson laboratory should make us extremely skeptical of the

usual assertions put forth by physician and layman alike.[44] His investigation dealt with 4,286 boys and 4,474 girls in a dozen different schools in England. A large number of correlation coefficients between intelligence, judged by school teachers, and physical condition, reported by medical examiners, were computed. These are summarized in Table 27. It is to be noted that his results for height and weight are in

TABLE 27

SUMMARY OF MEAN COEFFICIENTS OF CORRELATION BETWEEN TEACHERS' ESTIMATES OF INTELLIGENCE AND VARIOUS PHYSICAL TRAITS

(Heron. 1910)

MENTAL CAPACITY AND	MEAN OF PARTIAL COEFFICIENTS OF CORRELATION FOR CONSTANT AGE	
	Boys	Girls
Height	.10	.07
Weight	.06	.03
Condition of teeth	.08	.09
Nutrition status	.01	.08
Cervical glands	.09	.08
Tonsils and adenoids	—.01	.11

harmony with our critical review of the available evidence on this relationship. Negative results regarding the alleged deleterious consequences arising from bad teeth, impaired nutrition, enlarged cervical glands, and diseased tonsils and adenoids will doubtless be received by many with surprise. But the connection between such conditions and mental capacity is here demonstrated to be very slight indeed, as shown by correlations consistently ranging right around zero.

Our previous discussion of height, weight, and body build in relation to intelligence should have prepared us to find little or no demonstrable effect of malnutrition on intellect, since

[44] David Heron. The influence of defective physique and unfavorable home environment on the intelligence of school children. Cambridge University Press. 1910.

this condition is diagnosed on the basis of percentage deficiency in weight in relation to standard height-age norms. Furthermore, the results secured by Gates and reported in Table 25 showed only a slight positive correlation between nutritional status and Stanford-Binet mental age. Moreover, additional investigations concerning the alleged injurious effect of malnutrition upon mental development, could be cited pointing definitely to the same conclusion, namely, that there is but a slight connection between malnutrition and variations in mental capacity of children of a given age.

It would appear that mental development proceeds apace, little influenced by undernourishment. If we assume that our measures of intelligence reflect the condition of the higher centers of the central nervous system, we would be forced to conclude that nature has thrown safeguards around the central nervous system adequate to guarantee the continuance of mental development even in spite of adverse physical conditions. This view receives strong support from the observations reported by Professor Scammon in the concluding paper in this symposium to the effect that although gross malnutrition may exist sufficient greatly to retard physical growth or even to arrest it, yet the nervous system continues to grow, apparently at the expense of the bodily tissues themselves.

Assertions regarding the harmful mental effects of diseased tonsils and adenoids continue to be made in spite of Heron's demonstration to the contrary. These assertions frequently are accompanied by extravagant claims regarding mental improvement after removal of infected tonsils and adenoids. Perhaps citation of the careful investigation of Rogers will serve to confirm Heron's results and so provide a convincing answer to popular belief and unscientific medical opinion.[45]

Rogers arranged to have a group of 530 school children examined by a school nurse or physician and then subdivided

[45] M. C. Rogers. Adenoids and diseased tonsils, their effect on general intelligence. Arch. Psychol. No. 50. 1922. p. 1-70.

into two groups, one composed of those in whom the diseased condition of tonsils was pronounced enough to warrant medical treatment, the other composed of those in whom the tonsils were normal or so slightly defective as not to demand treatment. The Stanford-Binet *IQ*'s of these two groups of children were then compared, the median *IQ* of the 237 children in the

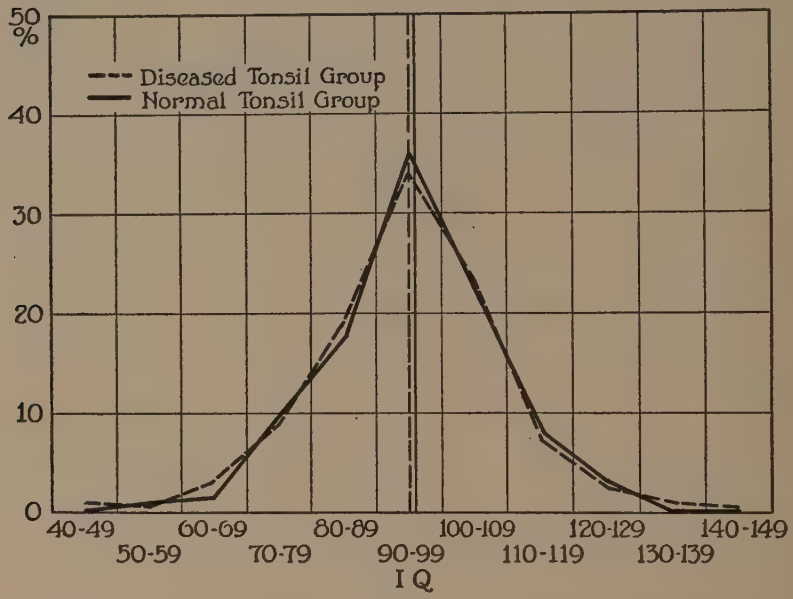

Fig. 59.—Percentage distribution of *IQ*'s for two groups of children, one group with diseased tonsils, the other group with normal tonsils. (Based on data in Table 28.)

diseased-tonsil group being 95.3 and the median *IQ* of the 294 children in the normal-tonsil group being 95.6 (see Table 28). The difference is almost imperceptible. Furthermore, when the *IQ* percentage distribution curves are plotted as shown in Figure 59, the two curves are almost identical, justifying the conclusion that the presence of diseased tonsils in the infected-tonsil group in no way impaired their mental development.

A more crucial test was reported by Rogers wherein a comparison of the *IQ* before and after removal of diseased tonsils

was made for 28 children. A control group of 28 children was also formed, each one of whom suffered from diseased tonsils but was not operated upon. The children in the operated group and in the control group were retested six months later. The

TABLE 28

SHOWING DISTRIBUTION OF *IQ*'S FOR TWO GROUPS OF CHILDREN, ONE GROUP CONTAINING THOSE SUFFERING FROM DISEASED TONSILS, THE OTHER GROUP CONTAINING THOSE WITH NORMAL TONSILS

(After Rogers. Arch. Psychol., No. 50. p. 29)

IQ	DISEASED TONSIL GROUP		NORMAL TONSIL GROUP	
	No. of Cases	Per Cent of Cases	No. of Cases	Per Cent of Cases
140–149	1	0.4	0	0.0
130–139	2	0.8	0	0.0
120–129	6	2.5	9	3.0
110–119	17	7.2	24	8.1
100–109	55	23.3	67	22.8
90–99	80	33.9	107	36.4
80–89	45	19.0	52	17.7
70–79	21	8.9	29	9.8
60–69	7	2.9	4	1.4
50–59	1	0.4	2	0.7
40–49	2	0.8	0	0.0
Total	237	99.1	294	99.9
Median	95.3		95.6	
σ	14.4		12.2	

average gain in *IQ* for the operated group was 2.25. But the control group, in the meantime, gained, on the average, 3.28 *IQ* points! To insure that these negative results were not due to shortness of time elapsing between operation and retest, a third mental test was applied after an interval ranging from ten to seventeen months following operation. The average gain

in *IQ* for the operated cases was 3.0, whereas the average gain in *IQ* for the control cases was 6.2. It must be remembered that the control children, during this whole period, continued to possess infected tonsils. It seems safe to conclude that no substantial improvement in *IQ* is discernible as a result of the removal of diseased tonsils either after six months or after an interval of one year. This conclusion might have been anticipated from the preliminary survey comparison, since there was no evidence that diseased tonsils had produced any mental retardation from which operated children could have recuperated.

When disease processes directly involving the central nervous system are studied for their possible mental sequalae, a very different picture is disclosed. For example, sleeping sickness (encephalitis lethargica) is now known to affect mental development profoundly in the great majority of cases, bringing about an apparently permanent arrest of mental growth.[46] Undoubtedly similar positive findings would be disclosed were intelligence tests applied to children suffering from spinal meningitis and other germ diseases attacking the brain. There is urgent need for cooperative research projects in this field—psychologist and physician combining forces to discover the precise effect upon intelligence of various disease processes and of such remedial techniques as gland-extract feeding, artificial sunbaths (Alpine lamp treatments), scientific vitamin diets, etc.

IV. SUMMARY

Man's search for an intimate connection between inner function and outer structure seems merely to reflect his universal tendency to think in terms of positive, rather than negative, relationships. The history of science itself shows there has been far keener interest in establishing a new relationship than in discovering the absence of a relation previously assumed to exist. Many there are who insist upon the scientific value of

[46] S. Dawson and J. C. M. Conn. Effect of encephalitis lethargica on the intelligence of children. Arch. Diseases of Childhood, 1: 357-368. 1926.

positive findings and deny, or at least disparage, the issue of negative results. With this in mind, the writer is quite prepared to see his audience somewhat crestfallen and disillusioned at the trend toward negative evidence manifest throughout our discussion of the relation between physical and mental development.

With the possible exception of physical factors associated with temperamental characteristics and of disease processes involving the higher centers of the central nervous system, our survey has demonstrated that prevalent notions regarding an intimate relation between bodily traits and mental development have been greatly exaggerated. Structural characteristics such as height and weight seem to be correlated with intellect to only a slight extent. Even precise X-ray measurements of skeletal development fail to show marked dependence of mental growth upon physical development. Indeed the evidence reveals that physical growth itself is far from being uniform. It appears that growth is highly specialized, with individual phases far less interdependent than most thinkers have assumed. Likewise, hope of finding positive relationships of greater magnitude by employing complicated morphological indices of body build seems to vanish when carefully controlled statistical investigations are actually pushed through to completion. And finally, ordinary physical defects and certain presumably deleterious physical conditions seem to be relatively unrelated to the enormous range of individual differences in intelligence to be seen on every hand.[47]

Of course, it must be understood that our presentation makes no pretense of deriving final answers to the questions before us. The initials P.U., standing for *plus ultra,* should be appended to every scientific formulation as an admission of its provisional character. Here we have merely tried to set forth

[47] A more extended treatment of the same topics covering all available quantitative studies during the past forty years has been completed. In all essential respects the conclusions are the same. See Donald G. Paterson. Physique and intellect. Century Psychology Series. The Century Co., New York. 1930.

as faithfully as possible the present state of our knowledge. Improved statistical techniques, discoveries of now unthought-of physical indices, invention of new modes of mental and physical diagnosis—all of these may at any time lead to positive findings contrary to those we now believe to be true. Furthermore, our available evidence has come wholly from investigations upon children of school age or upon adults, a fact that definitely precludes direct conclusions as to the facts for children less than six years of age. Therefore, the possibility that a closer connection between physical development and mental development may be discovered during the preschool period of childhood must constantly be borne in mind. In fact, the writer would urge those now investigating infancy and early childhood to repeat upon their subjects all the investigations reviewed in this paper in order to amass scientific knowledge concerning the period when physical growth and mental growth are proceeding at their maximum acceleration.

No more appropriate closing sentence for our present discussion could be found than Pearson's comment on the negative character of the results that he secured in investigating one single aspect of our problem, "Much of science is the verification or refutation of impressions and opinions, and the mainly negative conclusions of this paper place at any rate on a sounder quantitative basis the view that even for the mass, and therefore much more for the individual, little can be judged as to intelligence from the more obvious anthropometric measurements." [48]

[48] Karl Pearson. Relationship of intelligence to size and shape of the head and other mental and physical characters. Biometrika, 5: 105-146. 1906.

IV

THE MEASUREMENT OF THE BODY IN CHILDHOOD

By Richard E. Scammon

THE MEASUREMENT OF THE BODY IN CHILDHOOD

BY
RICHARD E. SCAMMON

IT is the purpose of this account to present a short summary of one phase of the measurement of mankind. This is the measurement of the body during its growing period—when the infant becomes a child and the child moves to man's estate.

This epoch of development includes approximately the first two decades of postnatal life. During this period the body is even a more labile structure than in maturity, and the great variability in all types of physical measurements of infants and children reflects the active response of the growing organism to the numberless exogenous and endogenous factors that play upon it. But in addition to these minor variations, the measurement of the body in its period of development reveals certain great trends of change which we commonly group under the rather vague titles of "growth" and "differentiation."

This discussion is concerned with the nature and course of these major trends of physical development in childhood rather than with the minor fluctuations of bodily measurements in this period. The latter are highly important from the practical point of view and have also great theoretical interest. But it is the former that primarily distinguish the young and growing organism from the mature one, and that justify a separate consideration of the physical mensuration of the child from that of the adult.

Everyone has always known that children grow, but the accurate and quantitative study of this growth began at a singularly late period in the history of natural science. In this, as in so many fields of investigation, the earlier and, in many instances, the more important discoveries were made by qualita-

tive investigation, by repeated clinical examination, and by the slow accumulation of casual information, methods that often lead to fairly certain conclusions without exact quantitative procedures. But in this field as in others that involve concepts of time and magnitude, the simple observational methods eventually reach the point of diminishing returns. And the further advance of our knowledge comes to rest upon the introduction of methods of precision in the collection and measurement of observations and upon the application of the techniques of graphic and numerical analysis to the data so collected.

The reason for the tardy adoption of the quantitative method in this phase of human biology is probably threefold. First, quantitative observations on the human body, like those of all other organisms, are subject to a very high degree of variability, for they include, not only the experimental errors that occur in the work of the physicist and chemist, but also the relatively tremendous variations due to different physiologic states and processes and the great inherent variability of all living things with which every observer of nature is familiar. Second, the student of human growth cannot control his observations, particularly as regards the time element, to the same degree as can the student of physical sciences. Third, the results obtained by these studies show a complexity that is rarely encountered in ordinary physical investigation. But these conditions should not deter us from the application of quantitative methods to the study of human growth. While they render the problem more difficult, they may be partially overcome by the accumulation of great masses of data to determine natural variability and by the development of a technique of quantitative exposition to meet the peculiar demands of this problem. When these conditions are fulfilled we may in time obtain results comparable in accuracy with those of the student of physical science and may, perhaps, make use of some of his methods in their interpretation.

The General Postnatal Growth of the Body as a Whole

Perhaps the simplest approach to the description of the growth of the body as a whole is through a consideration of the increments in what may be termed its general measurements. These are linear measurements of increment or dimensional growth, areal increment or the increase in surface of the body, and ponderal increment or increase in body mass or (within certain approximations) increase in body volume.

THE MEASUREMENT OF LINEAR GROWTH

The linear growth of the body is usually measured in terms of its increase in length or height, either of the body as a whole (stature) or of the body stem (trunk and head height, sitting height or stem length). I have chosen, as an introductory example of postnatal linear increment, the first complete set of seriatim quantitative measurements of human growth of which we have a printed record. This is a series of measurements of the increase in stature of a French boy from his birth in 1759 to later adolescence (1777). The observations were made by a French naturalist, Gueneau de Montbeillard, and published by Buffon (2). Figure 60 shows these data plotted in the form of a curve. The age in years from birth is indicated along the base line of the figure and the chronology of the measurements is shown along the upper margin. The figures at the left margin give the body height in the modern metric system and those at the right the same in the old French units of linear measure. It will be noted that this curve shows four rather definite phases. There is a period of rapid increase in infancy and early childhood; a middle period, extending from about three years to about twelve or thirteen years, in which growth is slow but constant, a period of marked acceleration around puberty, from about twelve to fifteen years; and a terminal period of slow increment thereafter.

Figure 61 is an example of modern work of the same character based upon the observations of Professor Martin Guttmann

of Vienna (8). It illustrates the increase in stature of four brothers. Each curve represents the progress of growth in height of a single individual (measured yearly) during the first two decades. It shows essentially the same characters as did the eighteenth century observations of Montbeillard, including the four marked periods of increased or diminished increment.

Professor Guttmann's data show some of the differences in size during the growth period encountered in members of the

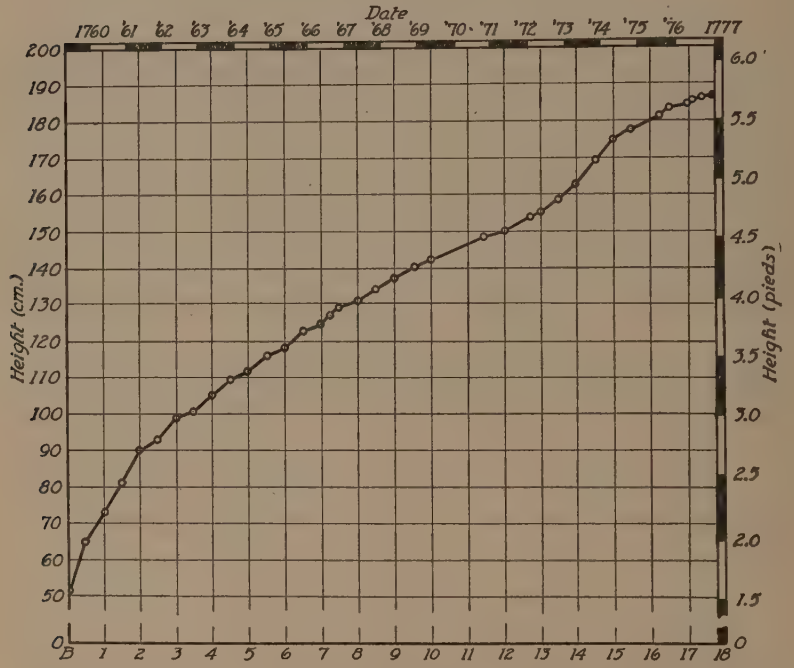

FIG. 60.—A graph illustrating the growth in height (stature) from birth to about eighteen years of a French boy of the eighteenth century. The figures along the base line of the graph represent the age of the subject in years. Those along the upper margin give the chronology of the measurements. The height in the original (old French) units of linear measure are placed on the right margin of the graph and their equivalents in the metric system are placed along the right margin. (Based upon the first published set of seriatim measurements of human growth, made by Gueneau de Montbeillard and published by Buffon (2).)

same familial group. If individuals of the same sex and heritage, living in the same environment, show such fluctuations in size, is it surprising that groups of individuals of the same age, but of diverse ancestry, social status, and nurture, exhibit high variability? Yet it is with this type of data that the student

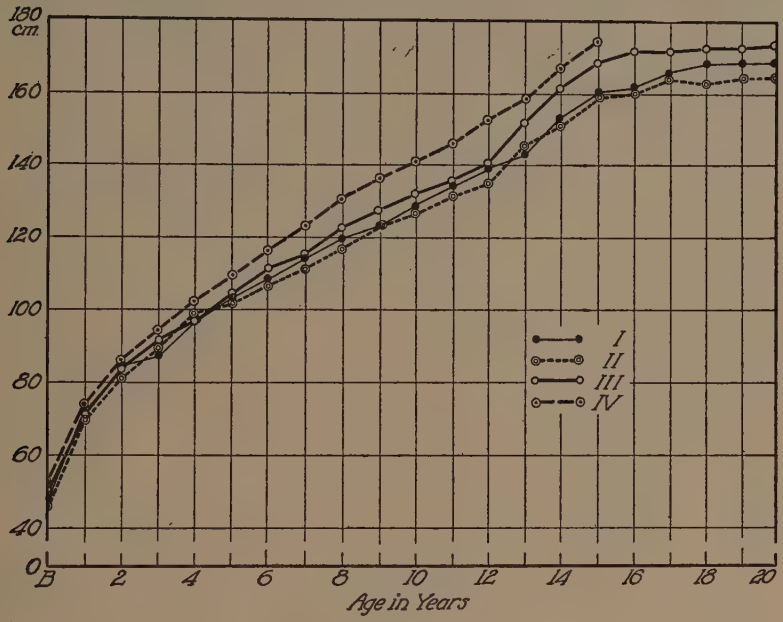

FIG. 61.—Curves illustrating the growth in stature, from birth to early maturity, of four brothers. The annual measurements are indicated by dots which are connected by lines. The birth orders are indicated by the Roman numerals on the chart. (Based on the observations of Guttmann (8).)

of human growth must work. Seriatim measurements of single individuals have been made, as the preceding examples show. But the process is exceedingly difficult and several scientific lifetimes would be required to obtain a sufficient number to represent a fair random sample of a population and to eliminate the technical errors of mensuration. Furthermore, seriatim measurements must be limited to external dimensions of the body and its orifices, and to those dimensions of internal struc-

tures that can be determined by radiography, auscultation, or other methods of physical examination.

On the whole then, while seriatim observations are of great value, we must depend largely on mass data for our knowledge of human growth, using as many observations as possible to assure fair sampling, rigorously excluding all cases which are *objectively* abnormal, and applying the best statistical methods

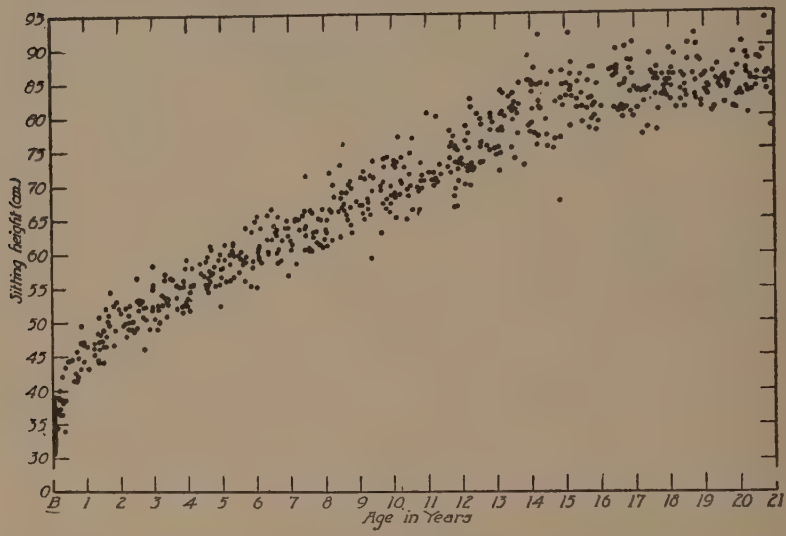

FIG. 62.—A field graph showing the distribution of sitting heights of 660 Minneapolis girls, 30 at birth and 30 for each year thereafter to twenty-one years. (From a series of observations collected by Dr. R. E. Swanson.) Abscissa: Age in years. Ordinate: Sitting height in centimeters.

available for the description of the central tendencies and variability of the material.

The pictures obtained by these procedures will be generic rather than specific. They will represent growth in populations rather than of persons. Some of the sharpness of the inflections associated with individual growth sequences will be lost in the general trends. But they will serve to illustrate the growth of man in the mass, which is our present objective.

Figure 62 shows a typical collection of mass data on linear growth and gives a fair concept of the scatter of individuals in a rather limited sample of population. It represents the sitting heights of 660 girls (30 at birth and 30 for each year thereafter to twenty-one years). Each observation is represented by a dot on the graph. Figure 63 is another representation of the same data. Here the *averages* of the observations for each year are

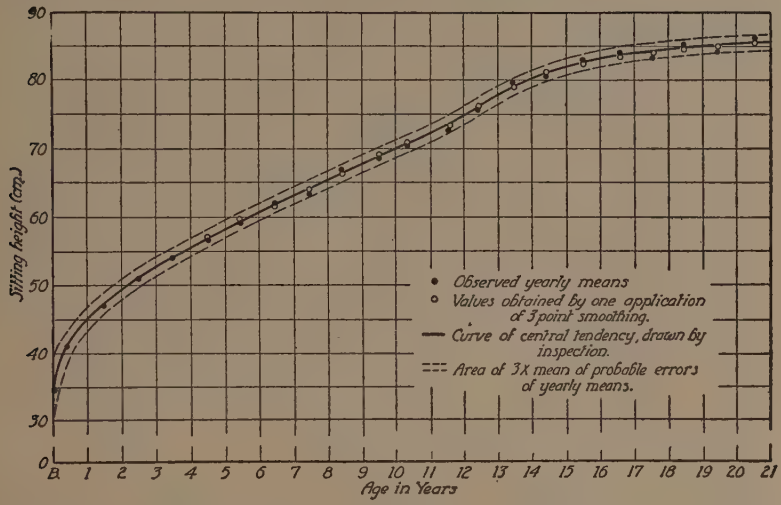
Sitting height (cm.)
90
80
70
60
50
40
30
0
B 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Age in Years
Observed yearly means
Values obtained by one application of 3 point smoothing.
Curve of central tendency, drawn by inspection.
Area of 3X mean of probable errors of yearly means.

FIG. 63.—A field graph of central tendencies of the observations on sitting height shown in Figure 62. The solid dots represent the mean values at birth and for each year thereafter to twenty-one years. The open dots represent the graduated means for the fifth year and over, as obtained by one application of the "three-point rule." The solid line is a curve drawn by inspection through the lower five "unsmoothed" means and the upper smoothed ones. The lighter broken lines on either side of the solid one representing the boundaries of a zone equal to three times the probable error of the observed averages.

represented by solid dots. The open circles represent an attempt to graduate these averages (after six years) by one application of the "rule of three-point smoothing," and the solid line passing through them is a curve of the central tendency of the progression, drawn by inspection. The two broken lines on either side of the solid ones represent the approximate limit of the "normal variation" (three times the probable errors) of the

observed means. Since these probable errors showed no definite trend with age, their mean has been used to establish zones of variability throughout the progression.

This curve representing the general trend in linear growth of this population shows essentially the same phases and points of inflection as do the preceding graphs representing the growth of single individuals. The chief effect of combining many observations is seen in the disappearance of minor irregularities from the progression.

THE MEASUREMENT OF AREAL GROWTH

The data on the postnatal areal growth of the body are not as satisfactory as those on stature, for the technical difficulties of this measurement are great, and no observer has been able to follow the course of increase in surface of a single individual for more than a few months. There are, however, some hundred and fifty single determinations of surface area at various ages in the developmental period. These are shown in graphic form in Figure 64. The individual observations are indicated by dots on this graph. The curve of central tendency has been drawn through them after one application of the rule of three-point smoothing to the median values.

These areal changes may also be represented graphically by plotting the *calculated* surface area, as determined from an empirical formula for obtaining area from weight and height, against time or age. Figure 65 is an example of such a curve. It is based upon the computations of Dr. Lugi Castaldi (3) and represents the calculated growth in mean surface area of a large group of Italian children as estimated from the well-known Du Bois (5) surface area formula. Both of these curves of growth in surface area show the same characteristics that distinguished the various progressions in stature—a rapid growth in infancy and early childhood followed by a period of slow increment in middle childhood, a second period of rapid growth prior to puberty, and a terminal phase of slower increment in adolescence.

THE MEASUREMENT OF PONDERAL GROWTH

The postnatal growth in weight or mass of the body may first be illustrated by some typical individual growth curves (Figure 66). These data are taken from the records of Professor Guttmann and represent the increase in weight of four

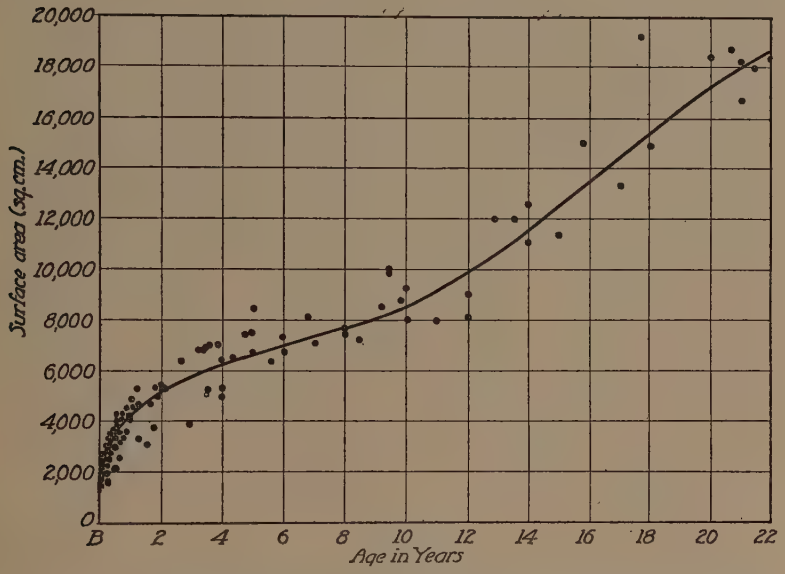

FIG. 64.—A field graph and curve of central tendency illustrating the course of growth of the body in surface area in postnatal life. The dots represent individual determinations of surface area by various observers. The curve of central tendency is drawn by inspection to the median values for the periods from birth to six months, six months to one year, one year to two years, and for two-year periods from two years to maturity.

brothers from birth to early maturity. They follow the same double sigmoid course that we have found characteristic of linear and areal growth, with some accentuation of the points of inflection of the progression and a more marked increase in the rate of growth in the years preceding puberty.

The growth in weight as determined from massed data is illustrated by Figure 67. This curve is based upon figures pre-

sented by Emerson and Manny (7), which in turn are drawn from several large sets of observations made in a number of American cities a number of years ago. In the figure the average weight of the body in pounds is represented by the horizontal lines on the graph while the vertical lines represent the ages in years. The heavy solid curve represents the average

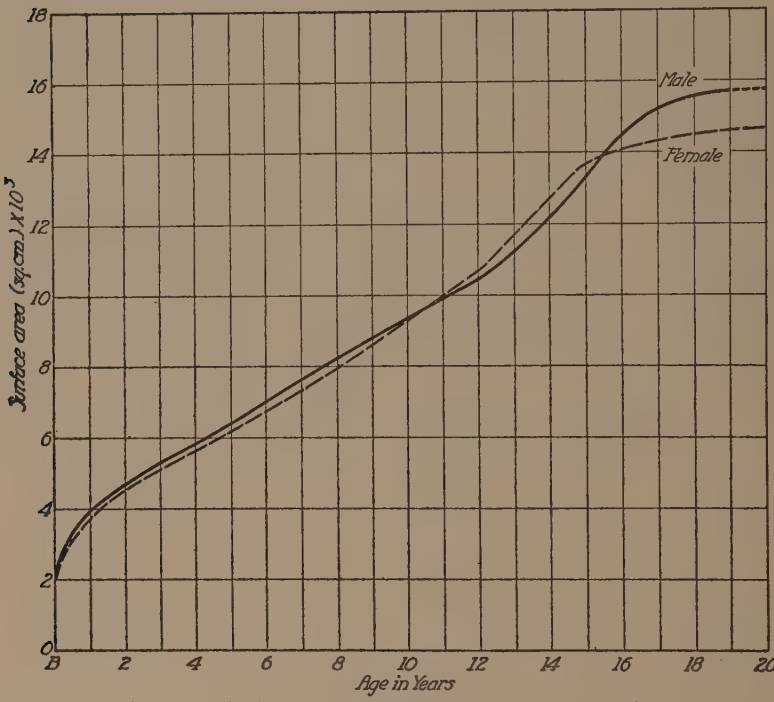

FIGURE 65.—A graph illustrating the increase in calculated surface area of the body in postnatal life. The curve is based upon the figures of Castaldi (3) obtained by applying the formula of D. DuBois and E. F. DuBois (5) [Area=(Body-weight) $^{0.425}$. (Body-length) $^{0.725}$. 71.84] to data on the heights and weights of Italian children.

growth in weight of boys, and the broken line the curve of growth in average weight of girls. Both of the curves show the same general phases that are seen in the individual weight curves.

It will be noticed that while boys and girls follow the same general course of growth, there are often marked differences in weight in the two sexes at the same ages. Thus, up to the prepuberal period the girls are, on the average, lighter than the boys. In the early part of the prepuberal period the girls are

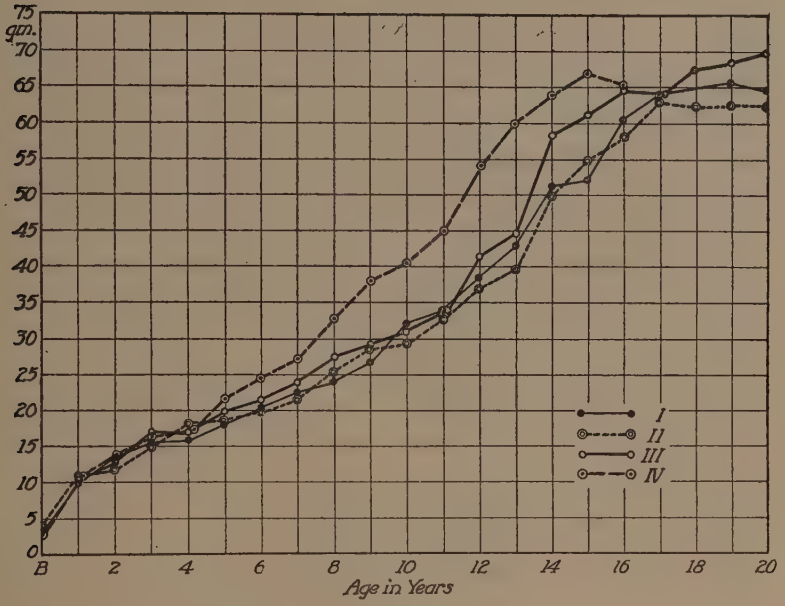

FIG. 66.—Curves illustrating the growth in weight, from birth to early maturity, of four brothers. The annual measurements are indicated by dots. The birth orders are indicated by the Roman numerals on the chart. (Based upon the observations of Guttmann (8).)

heavier. And in the latter part of the prepuberal period and in adolescence the boys again regain their lead in weight. This superiority in the size of girls in the few years preceding puberty is shown not only in their weight but also in their height, in their surface area, as is seen in Figure 65, and in many external dimensions. It is usually regarded as evidence that females pass through the various phases of the growth cycle a little more rapidly than do males.

The three measures of growth that we have just considered are quite unlike, for stature is a one-dimensional measure while surface area is a two-dimensional and weight is essentially a three-dimensional one. Consequently the relative postnatal increments in these magnitudes are entirely different:

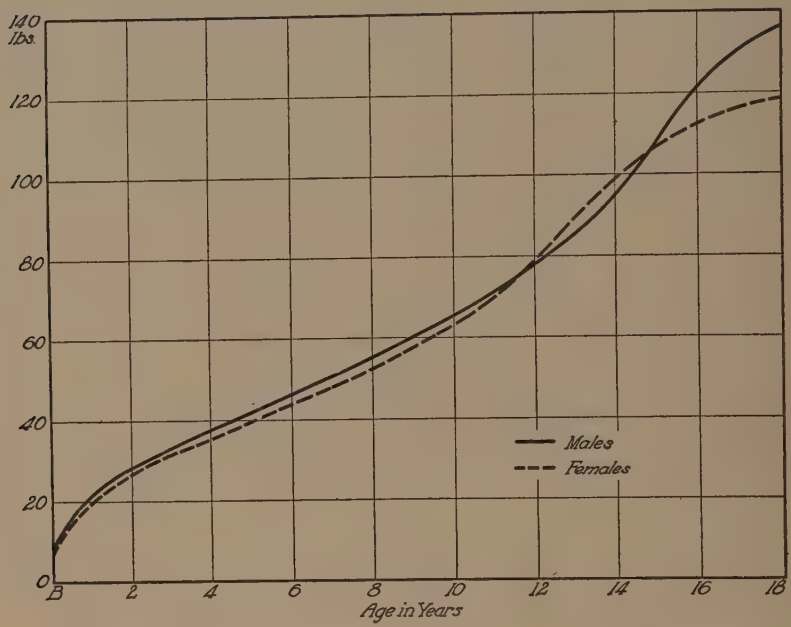

FIG. 67.—Curves showing the growth in weight of the body between birth and eighteen years. These curves are plotted to the figures contained in the average height and weight tables of Emerson and Manny (7). The values for these tables are based upon the data of Holt (revised figures) for American infants and on the data of Bowditch, Peckham, Porter, and others for older American children. In the Emerson-Manny tables the values after infancy have been "set forward" one-half year in an effort to adjust them to recent measurements of American children. Males, solid line. Females, broken line.

stature increases nearly three and one-half fold, surface area about seven fold, and body weight fully twenty fold between birth and early maturity. But regardless of the nature of the measurement selected and regardless of the method of its application—whether it be to the growth of a single individual or

to a population—we observe the same characteristic mode or course of increment. Since this style of growth is common to these diverse measures of the growth of the body as a whole, we may term it the *general* type of postnatal growth.

The Types of Postnatal Growth of the Various Parts and Organs of the Body

Turning from the postnatal growth of the body as a whole we may examine the changes in size of a number of its major parts and organs. They are illustrated in Figure 68. These structures are of diverse magnitudes, and they have been equated to a common standard in this chart by computing their weights at various years, not in absolute units but in per cents of their total gain in weight between birth and early maturity (twenty years). The first one represents the growth in weight of the body, based upon the figures of Emerson and Manny that have already been discussed. The remaining ones represent the postnatal growth in weight of the spleen, kidneys, pancreas, and liver, and the growth of the area of the heart silhouette.

It will be noted that in every instance these curves follow the same general course as do the general measures of growth of the body. In each case there is a period of rapid growth in infancy. Succeeding this is an interval of regular but slow increment in early and middle childhood. This is followed by a period of rapid parapuberal increase. And the progression is completed by a final period of slow increment characteristic of adolescence and, in certain instances, of early maturity.

While the amounts of growth in these various organs differ greatly, and the points of change of the several phases show some fluctuation, the general course of the progression is the same in all.

But this four-phased type of growth is not limited to the examples presented. Practically every external linear dimension of the body (exclusive of those of the head and neck), the di-

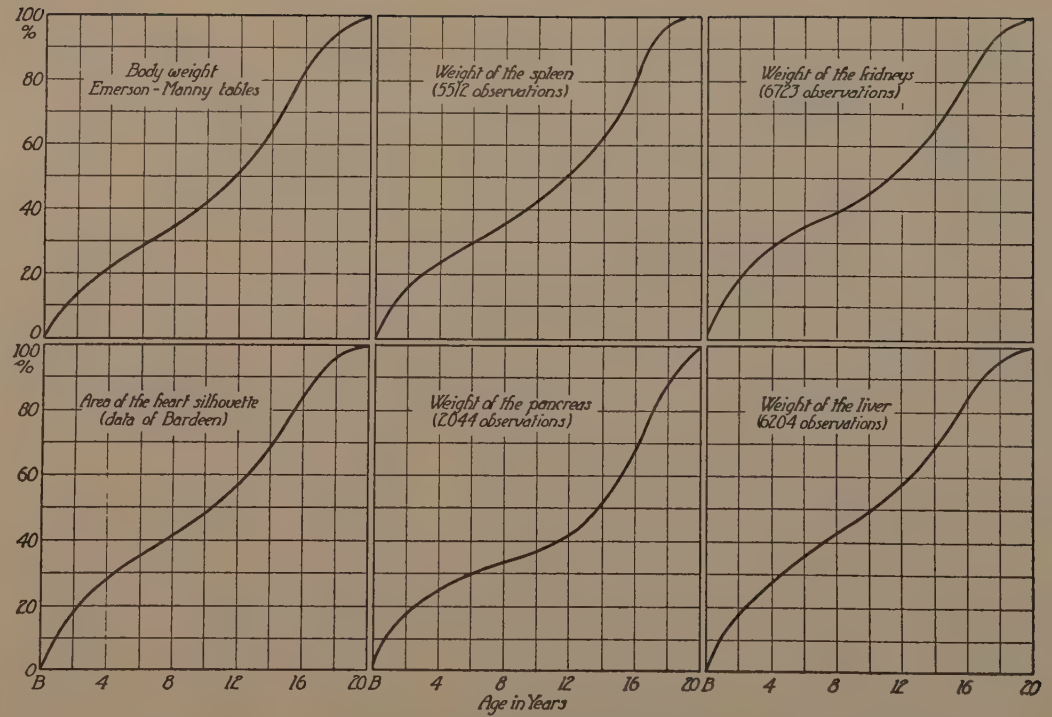

FIG. 68.—A series of six semischematic curves illustrating the course of postnatal increment in weight of the body as a whole and certain of its major organs. The curves have been reduced to a similar scale by computing the values of each measurement as per cents of its total gain from birth to early maturity (twenty years.) The curves were drawn to figures taken from curves drawn by inspection from the original data, with the exception of those for body weight and for the weight of the liver, that have been computed from analytic expressions fitted to the original data.

mensions of the respiratory system, and the weights of a number of the other viscera, the musculature as a whole, and the skeleton as a whole, follow this fashion of postnatal increment. Thus the *general* type of postnatal increment is common not only to measurements of the body as a whole but also to many organs and many of the minor bodily measurements.

Although the general type of growth is common to most parts of the body, there are other modes of postnatal increment which are followed by a number of important organs. Among these is the type characteristic of the brain and related structures. Figure 69 shows a series of curves of the postnatal increase in weight of the brain as a whole, the cerebellum, the brain stem (pons and medulla), the eyeball, and the pineal gland or body (epiphysis cerebri); and the growth in horizontal head circumference. As in the two preceding figures the differences in order of magnitude of these several measurements have been equated by computing the values at each age in per cents of the total postnatal increment (from birth to twenty years).

In each of these instances we find a phase of extremely rapid growth following birth to a variable time in infancy or early childhood with a rather sharp transition to a very slow growth phase to early maturity. In all instances these structures have attained above two-thirds of their adult size by the close of early childhood, whereas structures that follow the general type of growth have rarely gained over a quarter of their terminal or adult size by this time. Structures falling in this group always show this initial phase of rapid growth followed by a slower terminal one, although the durations of these two periods may be very different.

This type of growth is characteristic of the brain as a whole, of all its various parts and the membranes covering it, of the spinal cord, of the eye as a whole and its several parts, of several parts of the auditory mechanism and, in all probability, of the ocular muscles, the lachrymal gland, and the ethmoidal

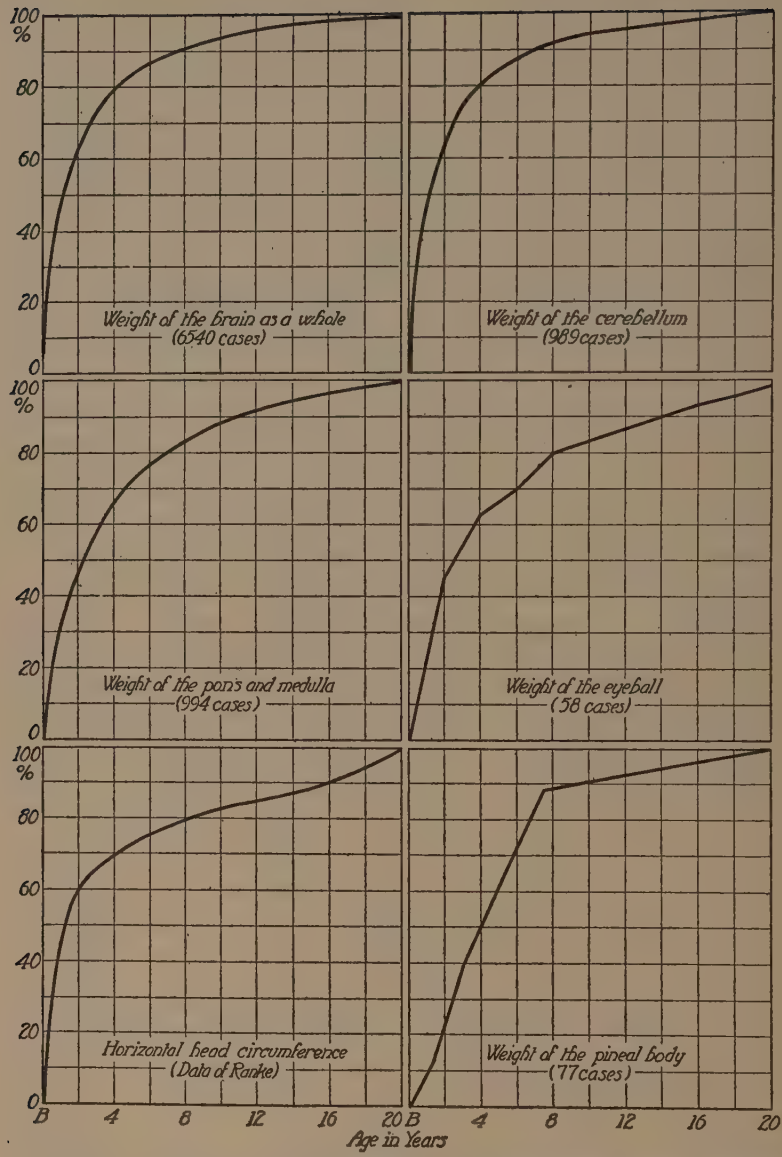

FIG. 69.—A series of six semischematic curves illustrating the course of postnatal increment of certain structures and dimensions following the neural type of growth in postnatal life. The curves have been reduced to a similar scale by computing the values of each measurement as per cents of its total gain from birth to early maturity (twenty years).

region of the nasal apparatus. It is also characteristic of many of the dimensions of the head, exclusive of the facial region. Since all structures exhibiting this form of postnatal increment are either of the nervous system or associated with it, we may term this form of growth the second or *neural* type.

Another group of structures that departs from both the general and the neural type of postnatal growth includes the majority of organs composed chiefly of lymphoid tissue. The available quantitative data on these organs are not so complete as one could wish, although they are sufficient to permit us to follow the general course of postnatal growth of most of them.

Figure 70 repeats the device used in the preceding figures of growth types and shows four lymphoid structures equated to the same order of magnitude by computing their sizes or numbers at each age level in terms of their growth between birth and twenty years. All show the same characteristics, a rapid rise in infancy and early childhood, a continued but slower increase to an apex about puberty, and a decline thereafter. Statistical studies on the number of palpable superficial lymph-nodes at various ages show these same changes, although the data are not of the type that lend themselves to graphic representation. Since the great majority of organs that are composed chiefly of lymphoid tissue follow this mode of postnatal increment, we may term it the third or *lymphoid* type of growth.

There is one organ in particular—the spleen—that contains a considerable amount of lymphoid tissue but that does not appear at first sight to follow the typical lymphoid mode of growth.

Curves of the postnatal growth in dimensions and mass of the spleen as a whole are obviously of the general type. But recently Hellman (10) made a quantitative volumetric study of the components of this organ and his figures show that the white pulp, which includes the greater part of the lymphoid tissue of the spleen, follows the lymphoid type of growth (Figure 71). We have here an interesting example of an organ with

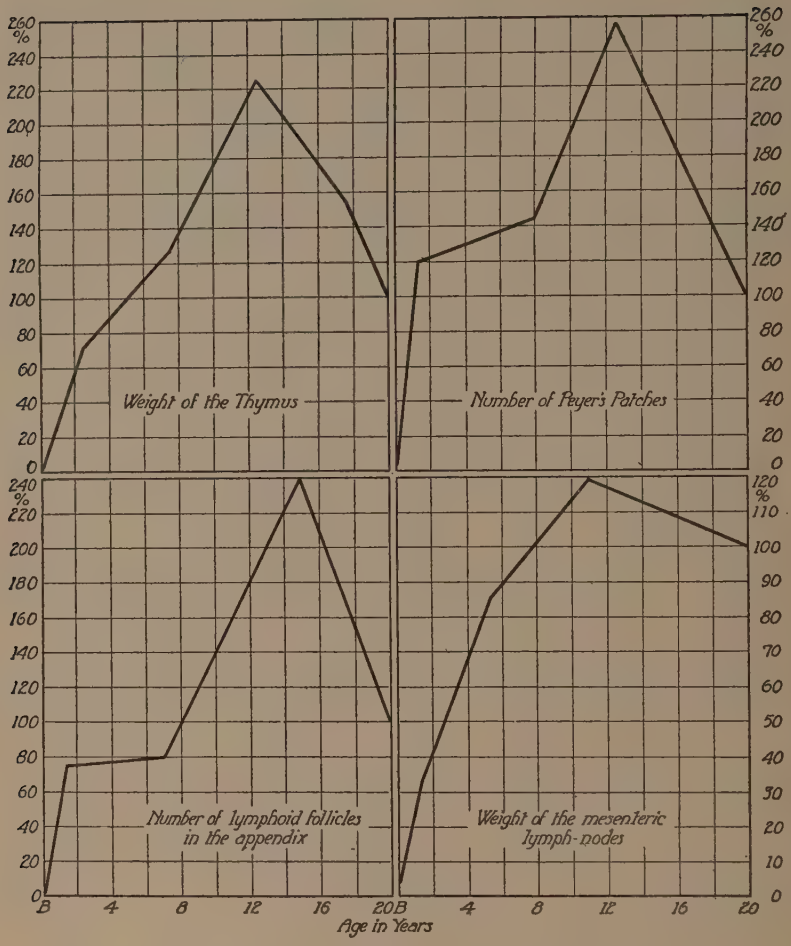
Weight of the Thymus
Number of Peyer's Patches
Number of lymphoid follicles in the appendix
Weight of the mesenteric lymph-nodes
Age in Years

FIG. 70.—A series of four semischematic curves illustrating the course of postnatal increment (and decrement) of certain lymphoid structures in postnatal life. The curves have been reduced to a similar scale by computing the values of each measurement or count as per cents of its total gain from birth to early maturity (twenty years). All values computed directly from observed means.

two styles of postnatal increase. The greater mass of the organ is formed of the red pulp which, according to certain modern views, acts mainly as a reservoir regulating the distributing of the blood content of the body. Blood volume, we know, remains fairly proportional to body weight throughout the post-

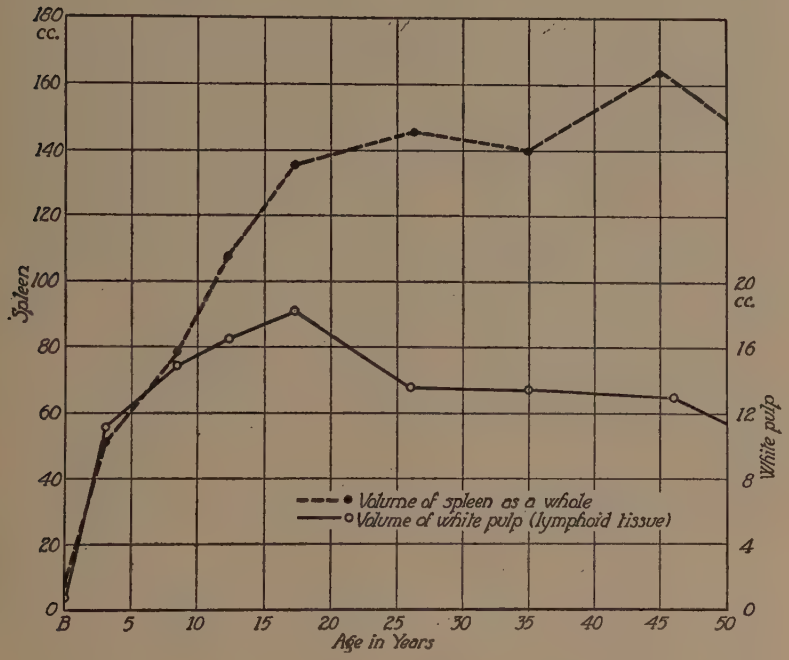

FIG. 71.—A graph illustrating the growth in volume of the spleen as a whole (broken line and solid dots) and of the white pulp or lymphoid tissue (solid line and open dots) from birth to late maturity. The dots represent mean values for five-year periods to twenty years and for ten-year periods thereafter. (Based upon the data of Hellman.)

natal part of the developmental period and must increase in the same manner as body weight. Therefore it is not surprising that the major part of the spleen follows the general type of growth but the lymphoid nodules embedded in the organ grow like other lymphoid masses.

There remains a fourth mode of growth, which is quite different from any of the preceding ones. This type is represented by the growth of the prostate gland, the testes, the epididymides, the seminal vesicles, and a number of other parts

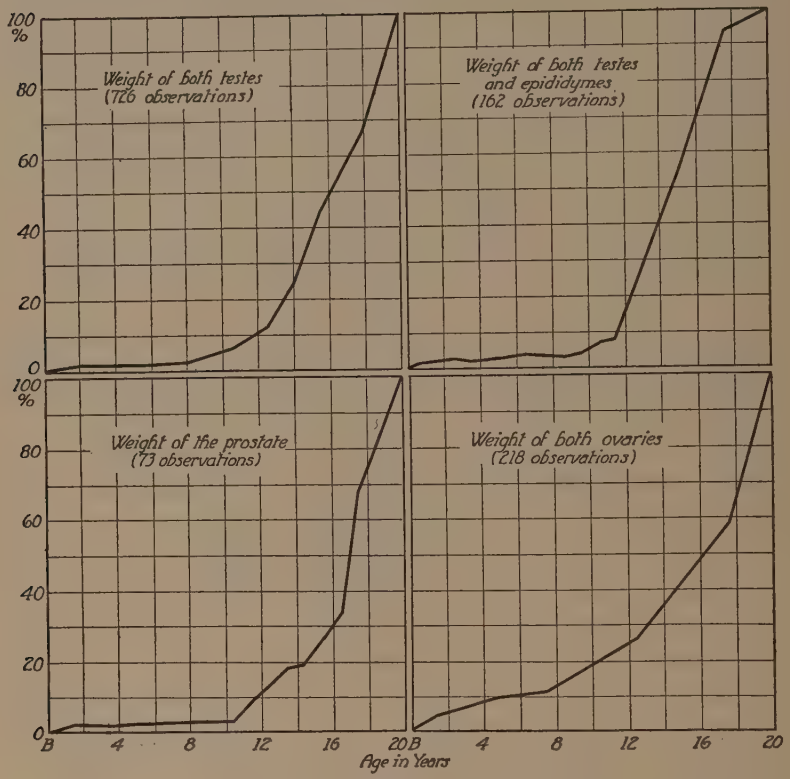

FIG. 72.—A series of four semischematic curves illustrating the course of postnatal growth in weight of certain organs of the genital system. The curves have been reduced to a similar scale by computing the values of each measurement as per cents of its total gain from birth to early maturity (twenty years). All values computed directly from observed means.

of the genital system in the male and by the ovaries and certain parts of the genital tract in the female. The course of postnatal increment of some of these structures is illustrated by Figure 72. These curves are all characterized by a slight rise in

infancy, a latent period or segment showing little change in magnitude from the close of the first year to the latter part of the first decade, and a phase of extremely rapid growth extending throughout the prepuberal period, adolescence, and, in some instances, a short period of early maturity. Linear dimen-

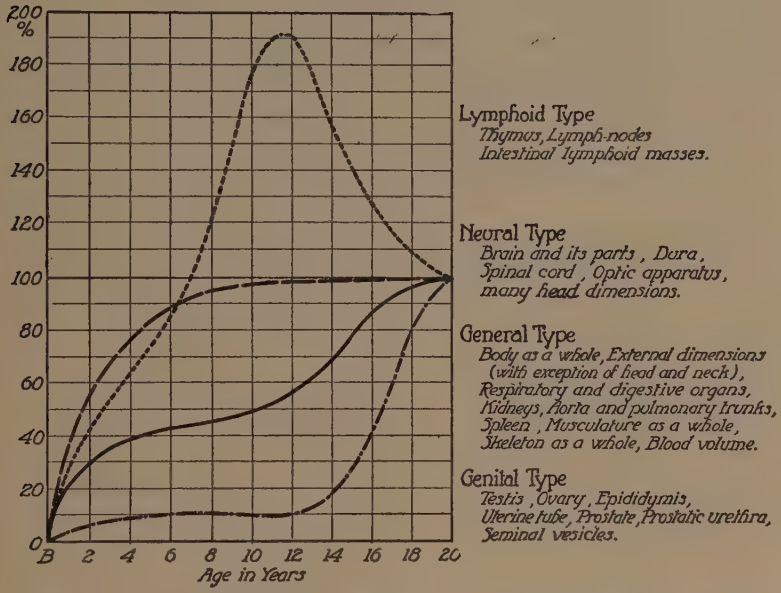

FIG. 73.—A graph showing the major types of postnatal growth of the various parts and organs of the body. The several curves are drawn to a common scale by computing their values at successive ages in terms of their total postnatal increments (to twenty years).

sions of these structures, as well as ponderal measurements, show these same changes. Since this mode of postnatal growth is characteristic of most of the genital organs, it may be termed the fourth or *genital* type of growth.

These four types of growth, general, neural, lymphoid, and genital, comprise by far the most frequent modes of increment in postnatal life. They are characteristic of the majority of the organs and parts of the body and of the greater number of the internal and external bodily dimensions. They are summarized

in diagrammatic fashion in Figure 73, which shows a typical example of each of these common modes of growth. As in the preceding figures the great differences in magnitude of the various organs have been equated by computing the growth of each structure as a per cent of its total increment between birth and the close of the second decade.

But there remain certain structures that fail to follow these common modes of increment and exhibit marked peculiarities in their growth histories.

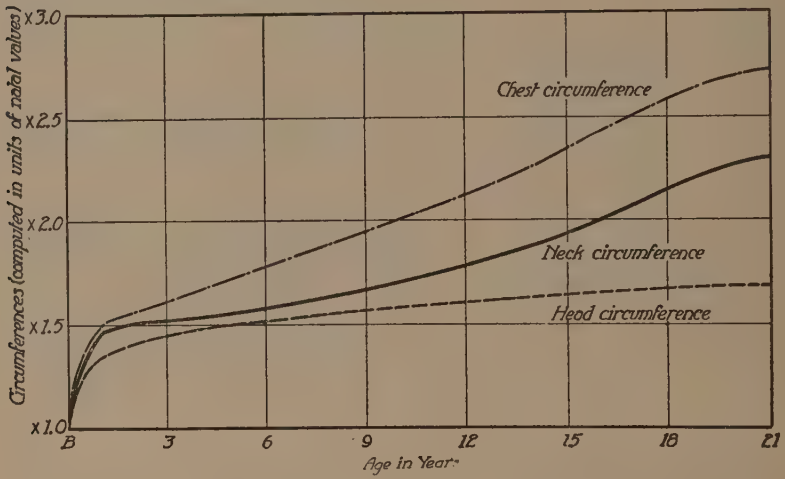

FIG. 74.—Curves illustrating the relative growth of the circumference of the neck, as compared with that of the chest and of the head. The values at each year (to twenty-one years) are calculated as multiples of the value at birth. (Based upon the measurements of Quetelet.)

The organs and parts that exhibit peculiar fashions of postnatal growth may be divided into two categories. A few are obviously *combinations* of primary growth types. Thus, for example, the circumference of the neck, like the head circumference, follows the neural type of growth in infancy and early childhood. But this dimension also shows a marked parapuberal increase consonant with the general body growth (Figure 74).

The second and more interesting category includes a number of organs with a variety of individual styles of increment. Perhaps the most striking of these are the suprarenal glands (Figure 75). These organs follow a typical fetal course of growth in prenatal life but within less than a fortnight after

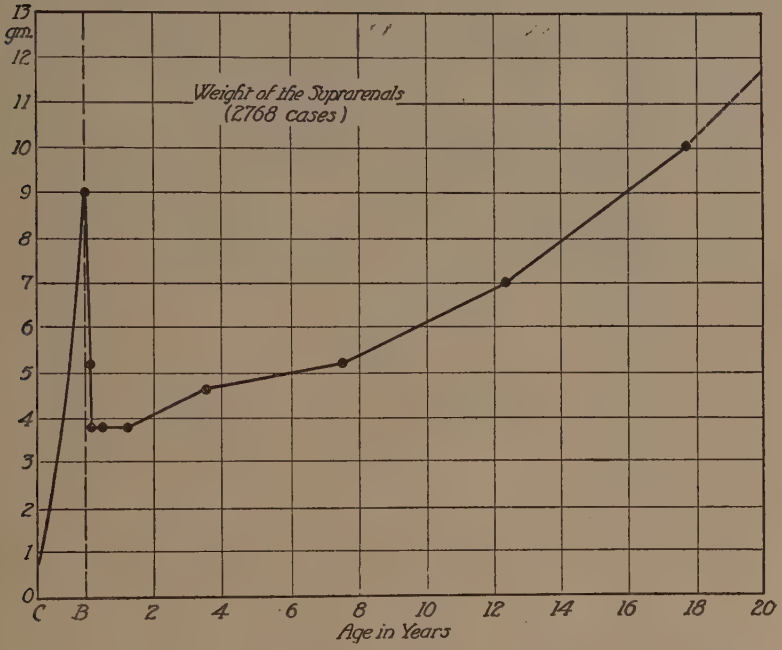

FIG. 75.—A curve representing the growth in weight of the suprarenal glands. The curve of prenatal growth of these structures is a calculated one based upon the empirical formula of Scammon. The "point-to-point" curve of postnatal growth connects mean values for the following periods: birth to thirty days, one to six months, six to twelve months, one to two years, two to five years, five to ten years, ten to fifteen years, and fifteen to twenty years. The broken line following the last average point extends to the mean adult value.

birth they lose one-half their natal weight and they show little evidence of ponderal increment during infancy or early childhood. Thereafter they enter on an irregular course of increment, but they do not regain their birth weight until puberty, and their weight in maturity is only double that of the new-

born. This remarkable neonatal change is due to the degeneration of the outer or cortical portion of the organs. Fully four-fifths of this portion of the suprarenals disappears at birth and regeneration does not become active until the approach of middle childhood. This phenomenon seems to be a characteristically human one although traces of cortical degeneration have been seen in some lower animals.

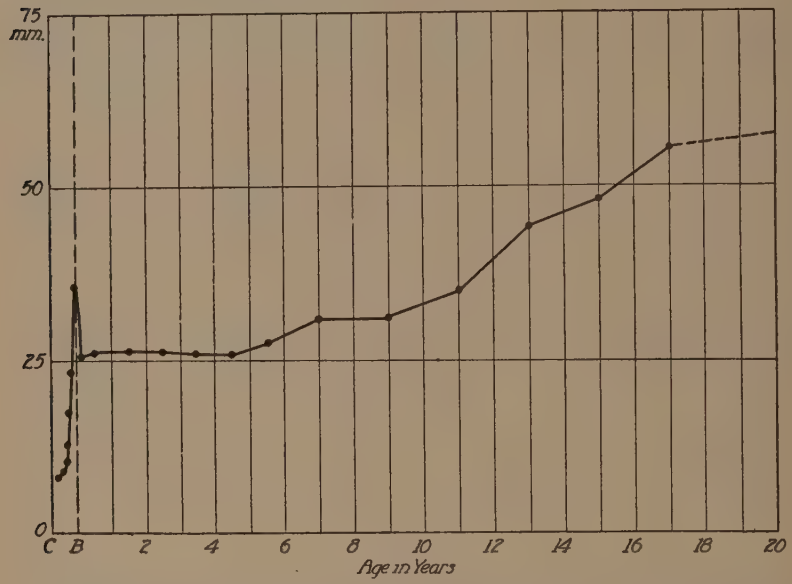

FIG. 76.—A "point-to-point" curve illustrating the growth in length of the human uterus in prenatal and postnatal life. The points represent average values in each lunar or fetal month from two months to birth in prenatal life. The average points in postnatal life are for the periods of birth to three months, three months to one year, yearly intervals from one to five years, and two-year intervals thereafter to eighteen years. The dotted line after eighteen years is drawn to the mean adult value of 60.5 mm. Based upon 635 observations.

Another organ with growth changes that superficially resemble these of the suprarenals is the womb or uterus. The growth of this structure, which is illustrated by Figure 76, is similar to that of most other organs and of the body as a whole in early prenatal life. But it enters on a phase of very rapid

increment at about seven lunar months and this is continued to birth. In the first two weeks after birth, as in the case of the suprarenals, there is a very marked decrease in size. After this change the organ follows the typical curve of the genital type, showing little increase to the close of the first decade and a rapid growth thereafter to puberty.

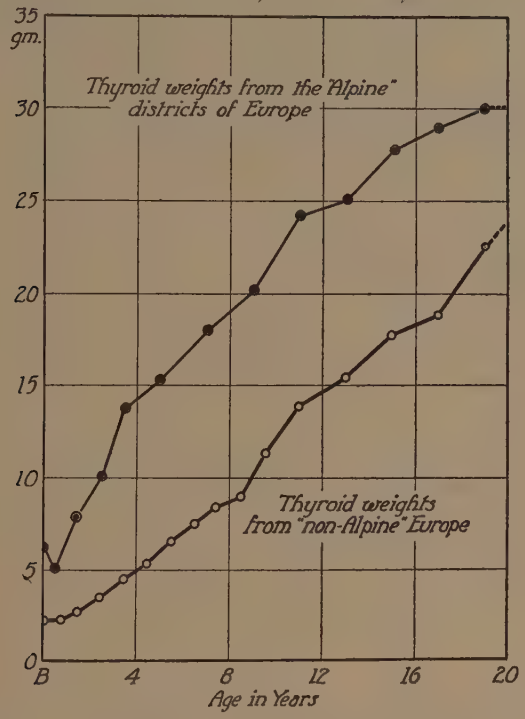

FIG. 77.—Two "point-to-point" curves illustrating the ponderal growth of the thyroid gland in postnatal life. The upper curve (light line, with means indicated by circled dots) represents the growth in weight of the thyroid gland as determined from records from the "Alpine" district of Europe (Switzerland, southern Bavaria, southern Württemberg, the Tyrol, Piedmont, and upper Lombardy). The lower curve (heavy line, with means indicated by open dots) represents the weight of the gland as determined from records from the coastal plains of Europe and the United States. The "Alpine" material is averaged for one-year intervals from birth to five years and by two-year intervals thereafter. The "coastal" material is averaged for one-year intervals to ten years and by two-year intervals thereafter.

Our data on the weight of the thyroid gland in infancy and childhood also fail to fit any of the typical curves of postnatal growth. Apparently the organ shows a fairly constant increment with respect to age, from birth to maturity, with little indication of more rapid growth in infancy nor, surprisingly, a parapuberal acceleration.

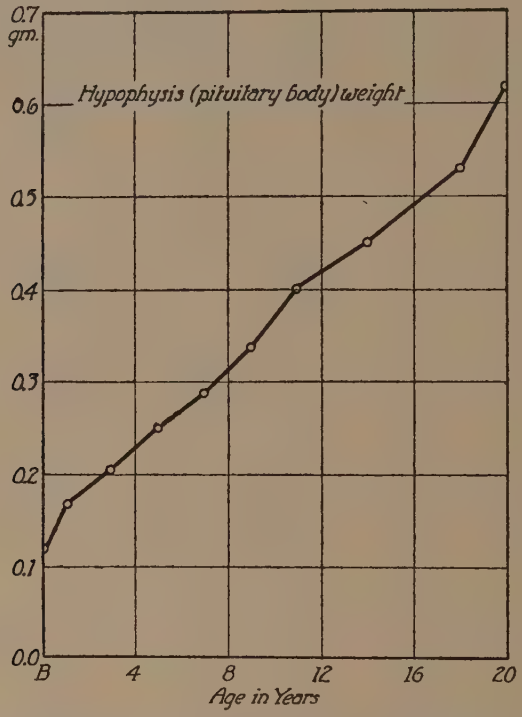

FIG. 78.—A "point-to-point" curve illustrating the increase in weight in the hypophysis cerebri (pituitary body) from birth to twenty years. The means are averaged for two-year intervals after birth.

Now it is well known that the thyroid gland varies greatly in size in different regions, being, perhaps, inversely related to the iodine content of the water and food supply of the inhabitants. The curve drawn in heavy line in Figure 77 may be considered typical of an "iodine high" district. It is based mainly

on records of specimens from the coastal plains of Europe, particularly the North Sea and Baltic littorals and the lowlands of Italy. All records in which pathologic conditions of the thyroid were noted are excluded from this series. The upper curve of this figure, which is drawn in light line, represents the growth in weight of the thyroid in the best known of the "iodine low" districts. It is based upon records from the Alpine district of Europe including Switzerland, southern Bavaria, southern Württemberg, the Tyrol, Piedmont, and upper Lombardy. These records were collected before prophylaxis against endemic goiter by the systematic administration of iodine or its compounds became general. All records in which pathologic conditions of the gland were noted were omitted from this series as from the preceding one.

The two curves show somewhat the same trend but the thyroid weight is much higher at every age level in the Alpine district. Also there is a noticeable drop in weight of the gland in infancy that I have not found in the "iodine high" series although Castaldi and Vannucci (4), and Aschoff (1) have observed it in their material.

The available data on the weight of the hypophysis or pituitary body in early postnatal life are still quite limited. They indicate a slow but steady growth of the structure from birth to maturity. The form of this curve (Figure 78) resembles that of the thyroid although the relative increment of the hypophysis is less in postnatal life.

It will be noted that several organs to which an internal secretion has been attributed are included in this group of structures with peculiar growth courses. Because of the great interest in the ductless glands, we may make a comparison of the postnatal growths of the several organs which are commonly listed under this category. Figure 79 is a chart of the same type as Figure 73 in which the increment from birth to twenty years of each of the organs is considered 100 per cent in order to equate the great differences in absolute masses.

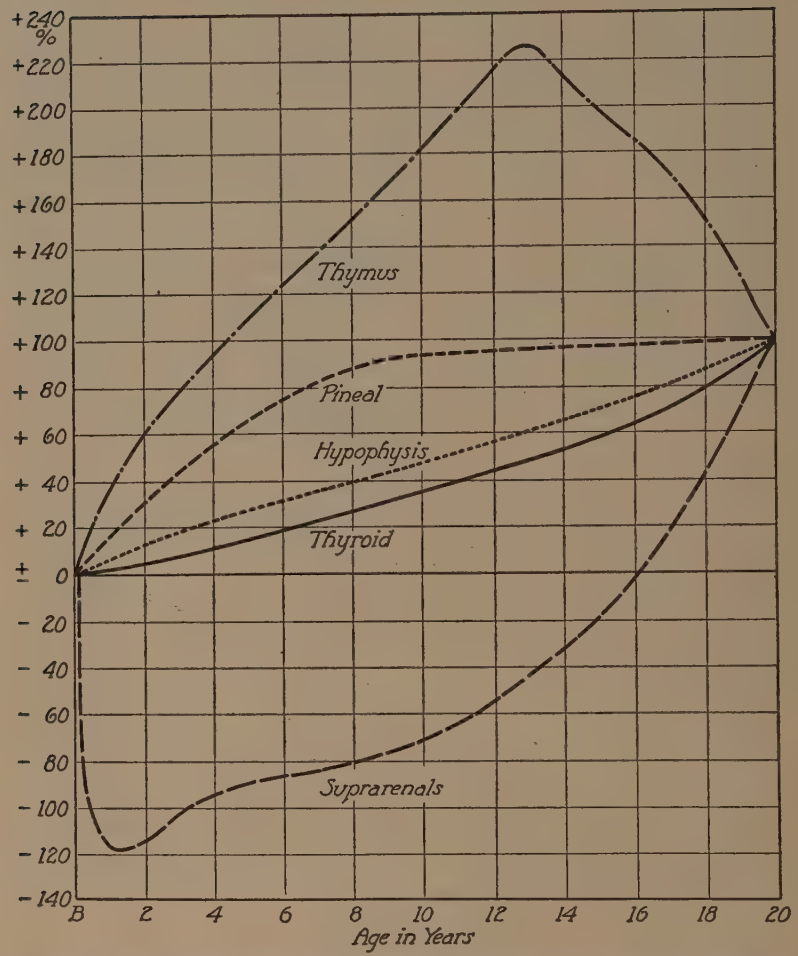

FIG. 79.—A diagrammatic graph showing the modes of postnatal growth followed by a number of the organs usually described as ductless or endosecretory glands. The curves are reduced to a common scale by computing their values at year intervals as per cents of their total postnatal increments (to twenty years).

The most striking feature of the graph is the utter lack of correlation in growth of these organs. The thymus follows the course of a typical lymphoid organ, rising to a maximal value at puberty and decreasing in size thereafter. The suprarenal

glands show a marked neonatal decrease, a long stationary period in childhood, and a rapid rise in prepuberty and adolescence. The thyroid and hypophysis follow somewhat parallel courses of growth with little change in rate from birth to maturity. The growth of the pineal body is suggestive, at least, of that of the nervous system. Thus these organs show as much dissimilarity in growth as they do in embryonic origin, topography, and structure.

A Comparison of Prenatal and Postnatal Growth

The postnatal growth of the body is clearly a complex of a number of types and fashions of increment which differ strikingly. Are these growth types, or their precursors, apparent in antenatal life as well? For several reasons this question cannot be answered completely in the light of our present knowledge. First, while the prenatal phase of human development is continuous, it is far from uniform. Some of the steps of this part of the human growth cycle are quite as abrupt and probably act even more potently upon fashions of growth than do the transformations that occur at birth. Second, while we have much qualitative information on the changes in the form and structure in the early part of prenatal life (during the period when the body is transformed from egg or ovum to an embryo) we have but little quantitative data on growth during this period. On the other hand, there is a huge mass of statistics on growth in the later or the *fetal* portion of prenatal life (20). The presentation must therefore be limited to this later or fetal period, which may be regarded as extending from about three lunar or fetal months to birth (at ten lunar months), and the relationships of certain great magnitudes of the body to age or time are reasonably well known.

Figure 80 shows a series of computed curves of the ponderal growth of the body as a whole and certain organs in the fetal period. The diverse magnitudes of these various measures have been equated, as in the preceding charts, by computing

the progressions in per cents of their terminal or birth values. Although care has been taken to select organs having the most diverse forms of postnatal growth it will be seen that the courses of growth of all are essentially the same. Each shows a period of slow growth in the early part of the fetal period, a

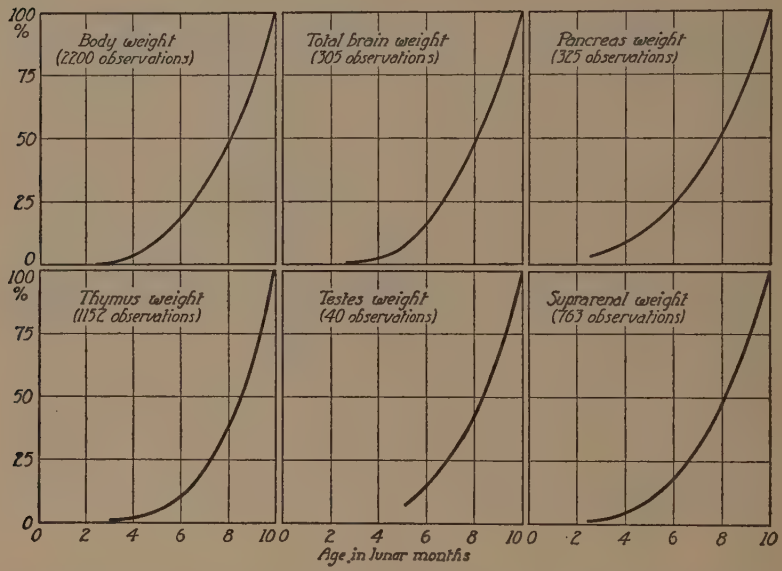

FIG. 80.—A series of six semidiagrammatic curves illustrating the prenatal growth in weight of the body as a whole and certain of its organs. The curves are reduced to a common scale by computing their values at each month as per cents of their respective natal values. A, total body weight, based upon the empirical formula of Scammon and Calkins. B, total brain weight, based upon the empirical formula of Dunn. C, weight of the pancreas, based upon the empirical formula of Scammon. D, weight of the thymus, based upon the empirical formula of Scammon. E, weight of the testes, computed from an empirical formula. F, weight of the suprarenal glands, based upon the empirical formula of Scammon.

rather marked change in rate about the middle of fetal life, and a rapid growth thereafter to birth. This rather simple course of ponderal growth seems to be characteristic of the body as a whole and of the greater number of its parts and organs in the later half of prenatal life. The differences in modes of growth

that are so striking in postnatal life are not found, at least by the methods here employed, in the prenatal period.

It is desirable to compare prenatal and postnatal growth by bringing these processes together on a similar although a somewhat distorted scale. This is done in the present instance by considering both growth and time in the prenatal and postnatal portions of the growth period as each equal to 100 per cent. A grid is constructed in which the ten lunar months representing age constitute 100 per cent of prenatal life (with each lunar month 10 per cent thereof), and the weight at birth represents 100 per cent of prenatal growth. Now the per cent of this weight attained at each fetal or lunar month will represent per cent of prenatal growth accomplished by this time.

In the same way a grid representing the developmental portion of postnatal life is constructed with ten panels, each representing two years, extending from birth to twenty years. The sum of these panels, representing age from birth to twenty years, is regarded as 100 per cent. The growth which is made by the body between birth and twenty years is also regarded as 100 per cent and is plotted at right angles to age or time. We may now compute the weight of the body and its various organs at any year in terms of its total postnatal growth and thereby obtain the per cent of postnatal growth which has taken place by this time. Now in this system of coordinates birth and birth weight are both 100 per cent with respect to prenatal life, and they are both zero per cent with respect to the postnatal part of the developmental period. Therefore, if we place our grids in such a way that the upper right-hand corner of the field representing fetal life is also the lower left-hand corner of that representing the postnatal period, the values at this point become identical and continuous curves may be drawn through the two grids showing the proportionate ponderal growth throughout the developmental period.

Figure 81 is an example of this form of compound graph illustrating the growth curves of the weight of the body as a

whole, the brain, the thymus, and the suprarenal gland. It thus contains an example of one of each of the structures following a major type of growth curve and one organ showing a dis-

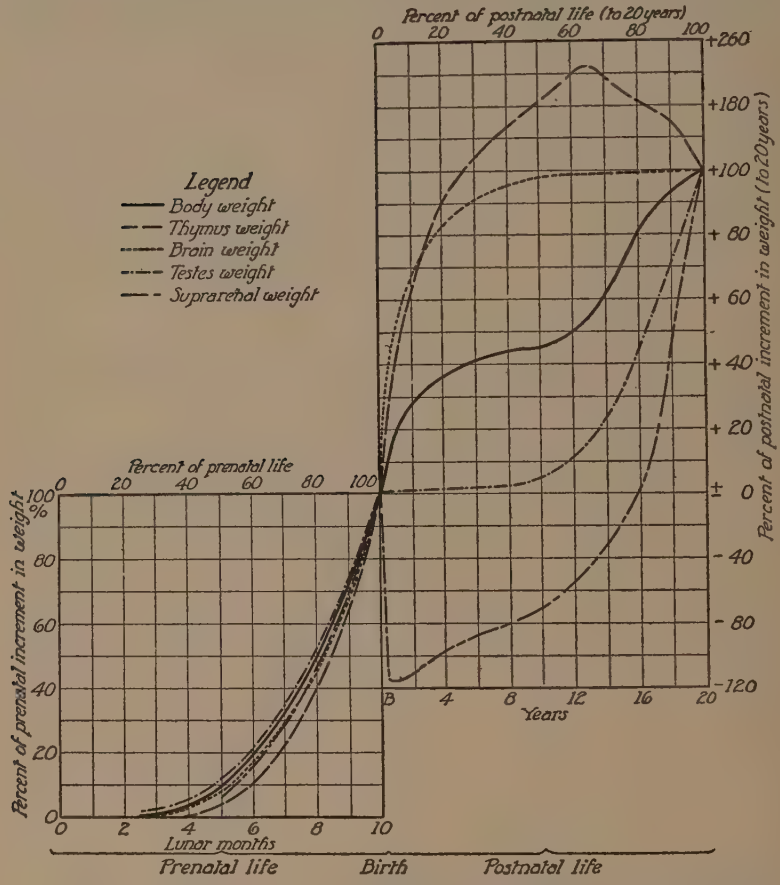

FIG. 81.—A diagram illustrating the growth in prenatal and postnatal life of a series of structures of diverse postnatal types of growth. The construction of this graph is described in the text (p. 203).

tinctly individual type of postnatal increment. It shows in graphic form the general principle already stated—the remarkable uniformity of prenatal growth and the equally striking diversity of course of postnatal increment. But this figure gives

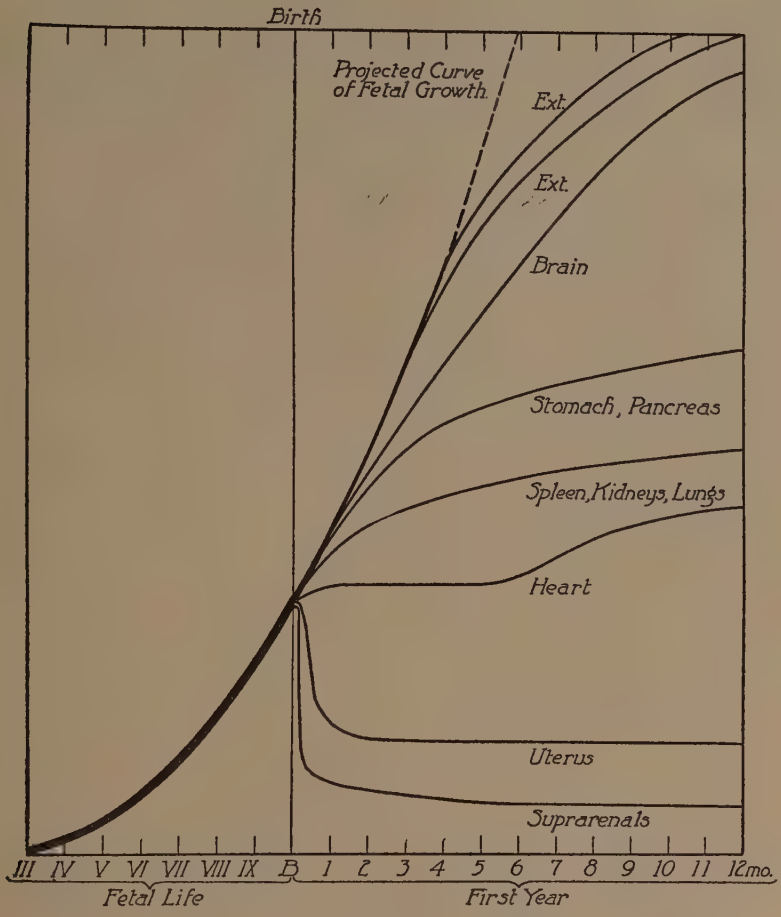

FIG. 82.—A diagram to illustrate the manner in which the various types of postnatal growth are differentiated, during infancy, from the simple type of growth curve characteristic of the fetal period.

one a somewhat false conception of the mode of transition from the fetal to postnatal modes of growth, for the change is not so rapid as the method of presentation indicates, and the characteristic form of growth of the fetal period seems to be frequently continued for the few months of infancy. This transition is illustrated in schematic fashion in Figure 82. Starting

at birth the uterus and suprarenals immediately drop away from the typical fetal curve. This is followed by a marked decrease in the rate of heart growth, which is probably functionally related to the loss of the vascular bed of the placenta. Next the major viscera assume their postnatal courses. Later the stomach and pancreas, that have possibly continued their growth due to functional stimulus in postnatal life, likewise adopt a slower rate of increment. This is succeeded by the differentiation of new and slower growth rates for certain parts of the nervous system, and, finally, among the last dimensions to abandon the fetal type of growth are certain measurements of the trunk and extremities.

Thus the transition from the uniform style of growth that is so striking in the fetal period to the diverse forms that are characteristic of extra-uterine life is not an immediate one, nor does it take place in all parts of the body at the same time. From the standpoint of growth, practically all of infancy may be regarded as a transition period, in which the organs and structures of the body are departing, one by one, from the simple style of increment characteristic of the fetus to the diverse and complex modes of growth that obtain in childhood.

Rates of Human Growth

Hereto we have expressed growth in terms of attained magnitude of the body or its parts at given times in the life cycle. These expressions have been given either in some absolute unit of measurement, such as grams or centimeters, or in some relative form, as the per cent of the magnitude at birth or maturity. Another method of approach is through the study of the rates of growth of the body and its various parts.

A rate of growth may be defined as the amount of increase in size per unit of time. Thus, rate of growth is expressed in much the same way as the velocity of a moving body, and using a concept that dates back to Plato, who considered growth to be a form of motion, we often use the term, velocity

of growth, for this measure. The mean or average rate of growth may be estimated for any interval of time, long or short, by subtracting the initial size of the body from its terminal one. But growth rates often show great changes in appreciable units of time; therefore it is better to define them for given instants in the developmental period. Such rates may be called instantaneous velocities. They may be represented in the symbolism of the calculus by the differential fraction dM/dT.

The computation of rates of growth is quite simple if we have sufficient data to permit us to plot the changing magnitudes of any growing organism against its age or time. If the curves of these relationships can be expressed in algebraic form so much the better, for then the velocities of growth may be calculated with some precision, but even when this symbolization is impracticable, the rates of growth may be estimated quite accurately by modern graphic methods.

Since instantaneous velocities may be obtained for any number of points in a growth curve, we may in turn plot these values as curves against time or age, and a new picture of the growth process is presented to us.

Let us now apply these tools to the examination of growth to representative examples of the four chief fashions of growth which we distinguished by other methods. The first results of this experiment are shown in Figure 83, which represents in the form of a curve the absolute instantaneous velocity of growth in weight of the body as a whole (in terms of grams per lunar month) plotted against age. In this, as in some of the preceding charts, the time scale is woefully distorted, for a panel of equal width is assigned to the prenatal and to the postnatal divisions of the developmental period. This device is adopted to avoid reducing the antenatal section of the curves to almost microscopic dimensions. Starting with a rate of increment of approximately 100 gm. per month in the fourth fetal month the rate rises rapidly to nearly 900 gm. per month

at birth. In infancy it drops almost vertically and, after decreasing more slowly in early childhood, passes into a phase of constant but slow increment at the close of the middle part of childhood.

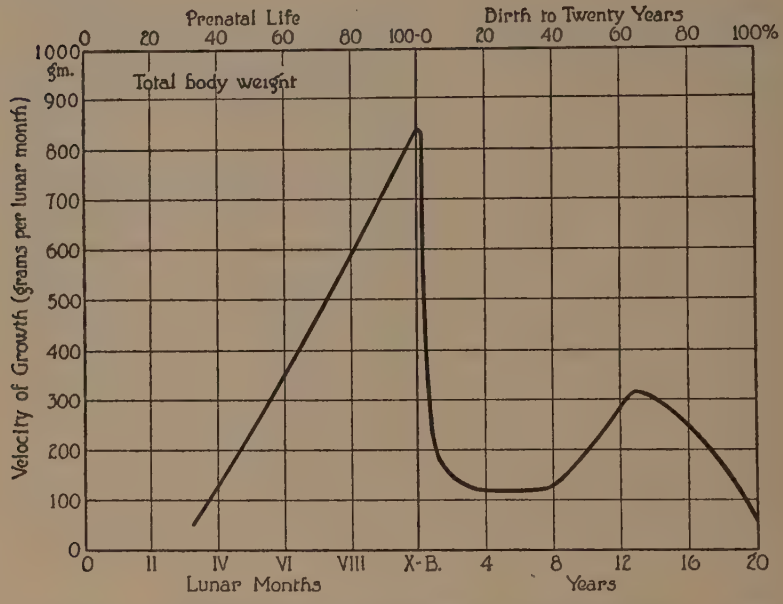

FIG. 83.—A semischematic curve illustrating the changes in absolute instantaneous velocity (grams per lunar month) of the total body weight in the developmental period. The time units of the left panel of the graph, representing the prenatal period, are in lunar months. The time units of the right panel, representing the postnatal life to twenty years, are in four-year periods. The segment of the curve representing prenatal growth is derived from the empirical formula of Scammon and Calkins. The curve of postnatal velocities is derived from a series of three empirical formulae fitted to the data of Emerson and Manny. The integral curve of the latter data is shown in Figure 65.

A second wave of increased velocity associated with, but definitely preceding, puberty makes its appearance near the close of the first decade. This reaches its apogee at about fourteen years and declines slowly thereafter.

Figure 84 shows the rate of growth in weight of a typical neural organ, the brain. The prenatal segment of the curve

is much like that of body weight although the acceleration is not as rapid. At birth the brain is growing in weight at a rate of over 100 gm. per month and the rate seems to increase a little in the early months of infancy. But following this is a

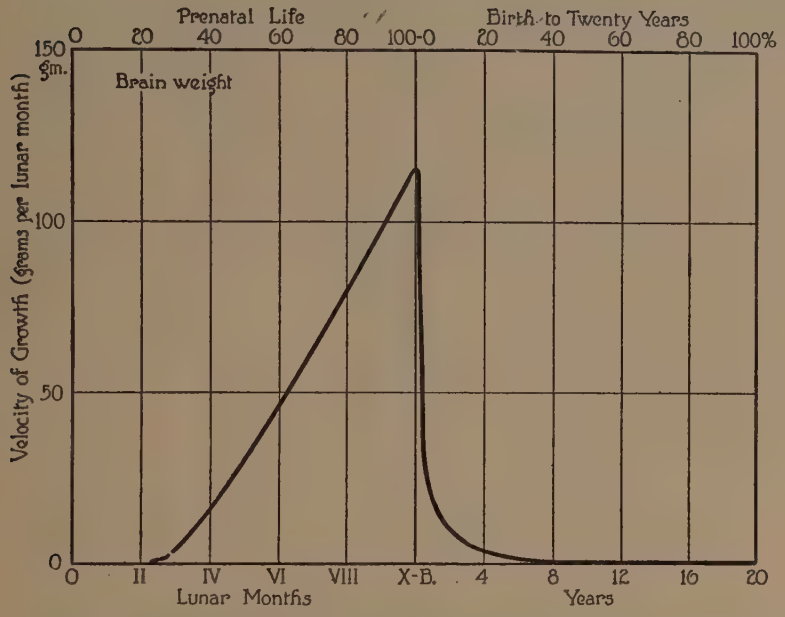

FIG. 84.—A semischematic curve illustrating the changes in absolute instantaneous velocity of growth in weight (grams per lunar month) of the brain in the developmental period. The time units of the left panel, representing the prenatal period, are lunar months. The time units of the right panel, representing postnatal life to twenty years, are four-year periods. The segment of the curve representing prenatal life is derived from the empirical formula of Dunn. The segment of the curve representing postnatal velocities is computed from the empirical formula of Scammon and Dunn.

period of rapid deceleration and the rate of growth at the close of the first year is only 25 gm. per month. The decline in rate is continued, although less abruptly, throughout early childhood and at four years the brain is growing at the rate of only about 4 gm. per month. Thereafter the rate of increment drops very slowly to zero in the latter part of the second decade.

The thymus, shown in Figure 85, illustrates changing rates of ponderal growth of a typical lymphoid organ. The rate of increment in fetal life resembles that seen in the preceding figures, showing a rapid rise from about one-tenth of a gram per month in early fetal life to nearly 4 gm. per month at birth. During infancy the rate declines very rapidly to one-half a

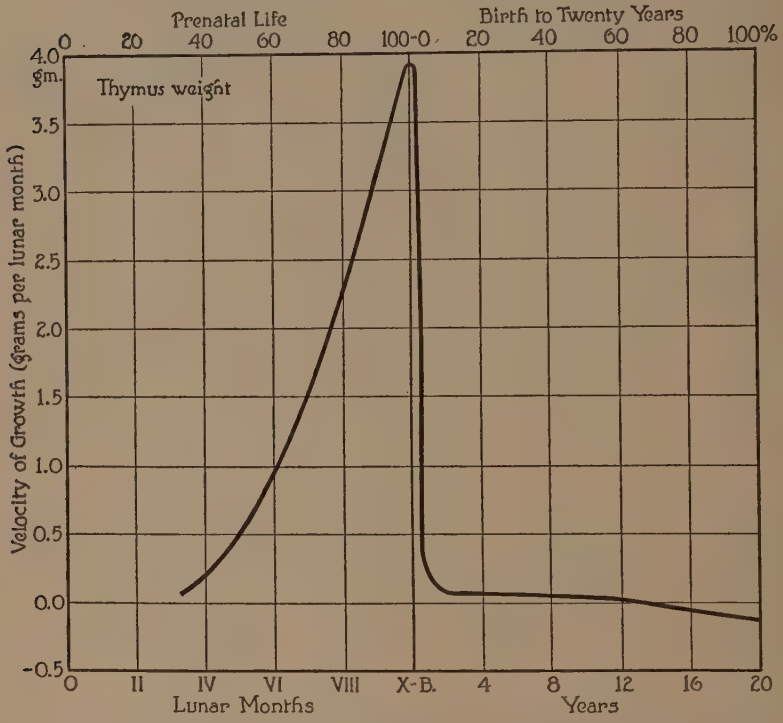

FIG. 85.—A semischematic curve illustrating the changes in absolute instantaneous velocity of growth in weight (grams per lunar month) of the thymus in the developmental period. The time units of the left panel, representing the prenatal period, are lunar months. The time units of the right panel, representing postnatal life to twenty years, are four-year periods. The segment of the curve representing prenatal velocities is derived from the empirical formula of Scammon. The segment of the curve representing postnatal velocities was obtained with a Latshaw tangentometer from a curve drawn by inspection to 600 selected observations on thymus weight.

gram per month at one year and more slowly to about one-tenth of a gram per month at two years.

There seems to be little change in rate of growth of the organ thereafter until about eight years when a second period of de-

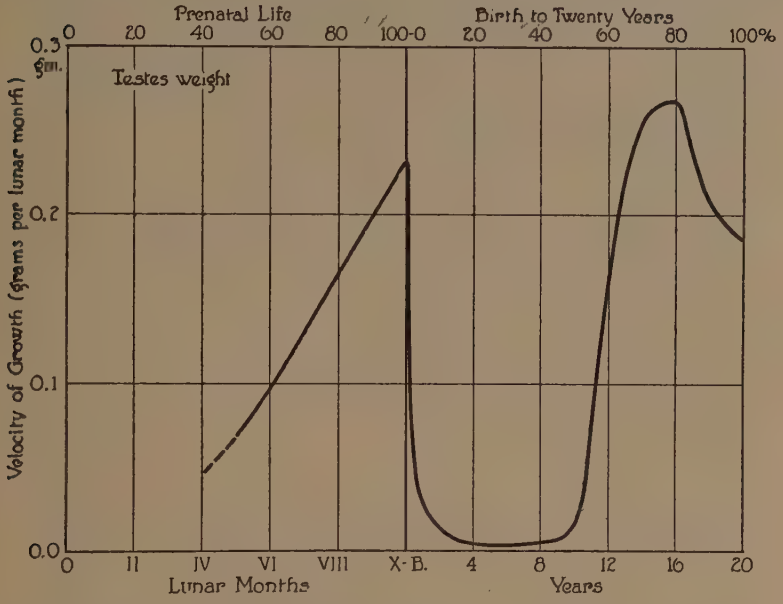

FIG. 86.—A semischematic curve illustrating the changes in absolute instantaneous velocity of growth in weight (grams per lunar month) of the testes in the developmental period. The time units in the left panel, representing the prenatal period, are lunar months. The time units of the right panel, representing postnatal life to twenty years, are four year periods. Both the prenatal and the postnatal segments of the curve are derived from empirical formulae for the relation of testes weight to age or time.

cline sets in. At about twelve years the rate is zero and subsequently it is negative, or in other words, the organ is decreasing in mass.

Figure 86 shows the growth history, in terms of rate, of a typical genital organ—the testes. Again there is nothing peculiar in the prenatal rate of growth of the organ and, like other structures, there is a rapid drop in rate in the first year. During

early and middle childhood the rate of increment is almost negligible. But at about ten years a second period of acceleration sets in reaching its maximum about the middle of the second decade, when the rate of growth, in contradistinction to that of the other examples in this series, is noticeably above that at birth. The rate of growth of the testes declines in the latter part of the first decade but is still high in early maturity when our observations end.

The phenomena that we have just considered have been expressed in absolute units and the rates of growth of the larger parts or organs of the body will obviously be greater than those of smaller ones. But growth rates may also be expressed in another fashion which makes the increments of parts of varying magnitudes or at different periods in development more comparable. This is done by computing rates of growth not in absolute units, such as grams or centimeters, but in terms of the magnitude of the growing object. In other words the rate of growth of the body (for example) at any given instant is divided by the size of the body at this instant. The resulting figure, which is usually multiplied by 100 to avoid extensive fractions and to give it the form of a percentage, is often called a *relative* instantaneous rate of growth. Strictly speaking it is a ratio rather than a true percentage for we have divided one thing, a rate, by quite another entity, a quantity, and in the following discussion figures of this sort will be called relative velocity ratios.

The pictures given by relative velocity ratios are quite different from those of absolute velocities but are equally instructive. We may follow the changes in the velocity ratios of the several organs selected as examples of the major types of human growth (Figure 87). At birth all of these structures are growing at a rate of between 5 and 10 per cent per month of their attained magnitudes, and all undergo a very marked reduction in this relative rate of growth in infancy and early childhood. But thereafter the trends of this measure of incre-

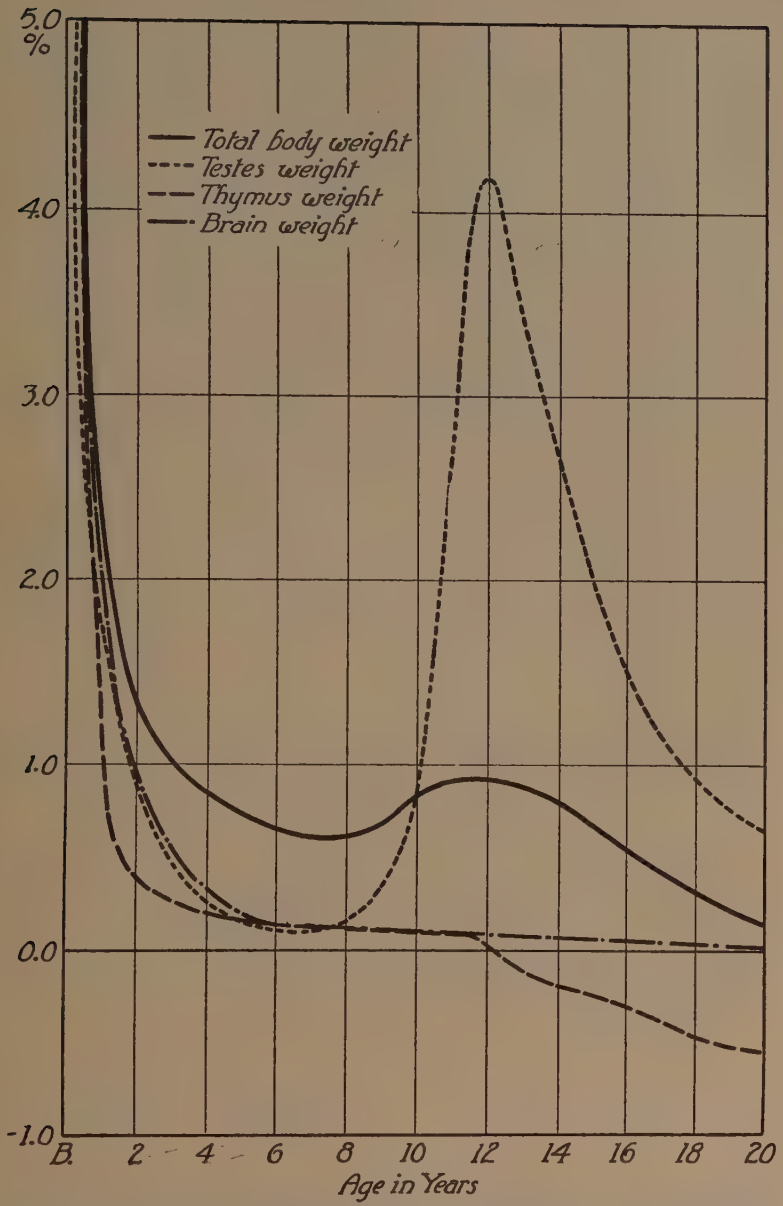

Fig. 87.—A set of semidiagrammatic curves illustrating the main changes in the relative instantaneous velocities (instantaneous velocity ratios) of growth in weight of the body as a whole, the brain, the testes and the thymus in postnatal life. (Source of material noted in connection with Figures 83 to 86, inclusive.)

ment become very different. The relative growth of the body as a whole (*the general type*) as exemplified by body weight falls to a minimum at about seven years but shows a distinct parapuberal rise to about twelve years and a decline thereafter. The genital organs (*the genital type*), as exemplified by the testes, show an even more pronounced reduction in relative growth rate but a tremendous prepuberal rise, which, like the rise in relative rate of growth of the body as a whole, reaches its peak at puberty and declines thereafter. The nervous system (*the neural type*), as represented by the brain, shows no rise in relative rate of growth in later childhood or adolescence. On the contrary, there is a steady but slow decline in this measure from middle childhood to maturity. And the lymphoid organs (*the lymphoid type*), as illustrated by the thymus, show not only a decline in relative velocity but an actual negative velocity (indicating a loss of weight) in the years following puberty.

Thus measures of rates as well as amounts of growth illustrate the essential similarity of prenatal growth and the remarkable diversity of the postnatal growth of the various parts and organs of the human body.

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